CRUSHED AMBO SANDSTONE AS A PARTIAL REPLACEMENT OF SAND FOR C-25 CONCRETE PRODUCTION

BY

ASHENAFI G/MESKEL

A Thesis Submitted to the College of Architecture and Civil Engineering for the Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

(Construction Technology and Management)

ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

OCTOBER 2018

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Advisor: Habtamu Hailu

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DECLARATION

I hereby declare that this thesis entitled **"CRUSHED AMBO SANDSTONE AS A PARTIAL REPLACEMENT OF SAND FOR C-25 CONCRETE PRODUCTION"** was composed by myself, with the guidance of my advisor, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or professional qualification.

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Signature Date

APPROVAL PAGE

This MSc thesis entitled with "**CRUSHED AMBO SANDSTONE AS A PARTIAL REPLACEMENT OF SAND FOR C-25 CONCRETE PRODUCTION**" by **ASHENAFI G/MESKEL** has been approved by the following examiners in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering (Construction Technology and Management).

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ABSTRACT

The construction industry in Ethiopia is rapidly growing from time to time. The need for materials used for this industry is increasing. One of the construction materials is concrete. Conventionally concrete made by aggregate and binders. Mostly river sand used as fine aggregate in concrete mixtures.

The utilization of river sand in concrete production depleted natural resource of sand and increases the cost because of scarcity. This study was conducted to see the suitability of crushed Ambo sandstone as a replacement of fine aggregate in C-25 concrete production.

Initially, river and crushed Ambo sandstone samples to be used in the concrete mixes were collected and their physical properties were studied. Five different concrete mixes having five mix proportions for both river and crushed Ambo sandstone (i.e. 100%NS+ 0%MS; 75%NS+25%MS; 50%NS+50%MS; 25%NS+75%MS and 0%Ns+100%MS) were prepared for C-25 concrete strengths using a water-cement ratio and cement contents of 0.5. Three samples were made for each mix design. The properties of these mixes have then been assessed both at fresh and hardened state.

There were nine samples of concrete cubes prepared and tested at 7th, 14th, and 28th days for concrete compressive strength with a mix ratio of 1:2:3 and water to cement ratio of 0.50. Based on the laboratory test results with full replacement of river sand by Crushed Ambo Sandstone, given the mean compressive strengths at 7th day was 21.66 MPa, while at the 14th day was 26.74MPa, and at 28th day was 34.68 MPa. It means that; it satisfied the requirement for C-25 grade concrete. As the cost of production of the fine aggregate of Ambo Sandstone quarry was 140 ETB per cubic meter, while the price of river sand from Legeher Market was 300 - 400 ETB per cubic meter. Therefore, Crushed Ambo Sandstone possesses minimum price than the river sand. However, it must be given emphasis that the crushed Ambo Sandstone must be washed thoroughly before use in construction projects.

Keywords: Crushed Ambo sandstone, Concrete, Compressive strength, Fine aggregate, Cost

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LIST OF ABBREVIATION

AASTU	Addis Ababa Science and Technology University
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
EBCS	Ethiopian Building Code Standard
ERA	Ethiopian Road Authority
CAS	Crushed Ambo Sandstone
CA	Coarse Aggregate
FA	Fine Aggregate
FM	Fineness Modulus
NS	Natural Sand
OPC	Ordinary Portland Cement
RV	River Sand
SSD	Saturated Surface Dry
W/C	Water to cement ratio

CHAPTER ONE

INTRODUCTION

1.1. Background

Ethiopia is one of the rapidly growing countries in Africa. The major area of development in the country is the construction industry. This sector mainly involves the construction of buildings, dams, roads, and bridges. These all construction normally requires concrete as the basic material of construction. For making concrete about 65%-70% used an aggregate. These aggregate are coarse and fine aggregate. [21]

Coarse aggregate can be obtained from the different quarry that is manufactured by crushing a basaltic stone. Fine aggregate is also a natural resource material that can be obtained conventionally from river basins. It is also manufactured as gravel in small size by crushing a basaltic stone. [27]

All the construction projects in Ethiopia are undertaken by using concrete with a mix from river basin fine aggregate. The rapid extraction of sand from the river bed causes problems like deepening of the river beds, loss of vegetation on the bank of rivers, disturbance to the aquatic life as well as agriculture due to lowering the water table in the well etc. Therefore, construction industries of developing countries are under stress to identify alternative materials to replace the demand for river sand. [2]

To minimize these problems and to keep the environment from natural disaster there must be necessary to investigate another material that can fully or partially replace fine aggregate or river basin sand. [5]

Sandstone is one of the materials that are abounding available in the country. Ambo sandstone is mostly used to construct masonry parts of the building and also necessary for the decorative purpose. The crushed ambo sandstone believed to replace the fine aggregate.

The source of ambo sandstone is ambo town which is about 150 km far from the capital. This material is a sedimentary rock and has a different color like red, yellow, and white. Crushed ambo sandstone is a material of high quality. The fine particle and irregular shape of crushed ambo sandstone have a harsh effect on the workability and finishing ability of concrete. These harsh effects have given crushed ambo sandstone a poor reputation in the construction industry. However, recent studies have shown that this crushed sandstone can be used to produce concrete with high compressive strength and quality. [22 & 24]

The crushed sandstone based on its quality can replace 15 to 60% of total fine aggregate in concrete. The Ambo sandstone is yellow to red and predominantly fine-grained. The sandstone is quite porous, and therefore easy to split and shape. The color which is reddish at the surface changes into white as the stratification depth continues, the grains are very fine in texture and dusty in dry condition. The uses of crushed Ambo sandstone desirable from the environmental and social view point. It also needs economically and technically viable. [28 & 24]

1.2. Statement of the Problem

In the future aggregate, prices are expected to rise due to a decrease in sand deposits, quality and more environmental and land use regulations, which are associated with the rapid urban expansion that contributes to these shortages. Therefore, the importance of finding substitute sources of fine aggregate for concrete products that can be used in place of natural river sand cannot be overemphasized. [8]

In recent years, concrete has diversified its production. This condition is affecting the aggregate consumption indirectly. In addition, demand against current concrete economic conditions is good with an increase in aggregate demand. In these situations, it is not appropriate to rely on one source of aggregate with a continuing increase in demand and it will cause the shortage by natural fine aggregate in the future. Thus, several alternatives should be established for the preparation of the possible effects on the river-sand demand in the future.

In this regard, on the possible alternative material that can be used as a replacement for natural sand is the use of sandstone. Due to the forecast shortfall in the supply of natural sands and the increased activity in the construction sector, it is apparent that time will come, when sandstone may play a significant role as an ingredient in concrete production.

In Ethiopia, the Ambo Sandstone is only used for the decorative purpose of the external wall. This mineral found in Ambo town and transport to the capital of the country before dressed to the needed shape. After it arrives the irregular part is chiseled and unwanted part is stored as waste without any usage. To this effect, this research conducted on studied the usage of crushed ambo sandstone as replacement of river sand.

1.3. Objectives

1.3.1. General objective

The research objective was to study Crushed Ambo Sandstone as a partial replacement of sand for C-25 concrete production

1.3.2. Specific objectives

- To determine the effect of crushed Ambo sandstone on the compressive strength of concrete.
- To identify the optimum mix of concrete by using crushed Ambo sandstone.
- To evaluate test results with standards specifications.

1.4. Research Question

The research questions that this study explained as follows:

1. What is the potential effect of using crushed Ambo sandstone on the compressive strength of concrete?
2. Which one of the mixes is optimum to use crushed Ambo sandstone in concrete?
3. Does the results of the test show equivalency with international standard and specifications?

1.5. Significance of the Study

This study examined the effectiveness of the use of crushed Ambo sandstone produced from sedimentary rock by conducting strength test. It is hoped that this study will be the beginning of efforts to use crushed Ambo sandstone in construction material in the future. In addition, the outcome of this study provided:

- To provide important information on the physical properties of CAS to the local construction industry.
- To provide local concrete industry and practitioners' necessary information regarding the application of CAS as a replacement of river sand for producing concrete.
- To provide CAS as an alternative for river sand in concrete mix used for local contractors.

- Other researchers will use the findings as a reference for further research on the compressive strength of concrete.

Most importantly, it will reduce the use of limited natural fine aggregate and it can provide a cost-effective solution in terms of present and future concerns [8].

1.6. Scope and Limitation

The study focused on the effectiveness of the use of crushed Ambo sandstone produced from sedimentary rocks. Moreover, the focus of the study was also limited to the compressive strength of concrete cubes that contain crushed Ambo sandstone.

CHAPTER TWO

LITERATURE REVIEW

2.1. General

Different researchers have studied the replacement of river sand by different crushed or manufactured sand. So, in this chapter provided literature and investigation on concrete materials, fine aggregate, effects of river sand on concrete production, environmental and technical defects of river sand, the property of fresh and hardened concrete finally replicable material for river sand was discussed.

Concrete is a ubiquitous material and its versatility and ready availability have ensured that it has been and will continue to be of great and increasing importance for all types of construction throughout the world. [25] Many structures have concrete as their principal structural material, either in a plain, mass form, as for example in gravity dams, but more often as a composite with steel, which is used to compensate for concrete's low tensile strength thus giving either reinforced or pre-stressed concrete.

2.2. Concrete Making Material

Concrete is a composite material made by combining cement, supplementary cementing materials, aggregates, water, and chemical admixtures in suitable proportions and allowing the resulting mixture to set and harden over time. [21]

The quality of the paste and aggregates dictates the engineering properties of concrete construction. Paste qualities are directly related to the amount of water used in relation to the amount of cement. The less water used, the better the quality of the concrete. Reduced water content results in improved strength and durability and reduced permeability and shrinkage. Fine and coarse aggregates make up 60 to 75% of the total volume of the concrete; therefore, selection of aggregate is important. Aggregates must be of adequate strength, resistant to exposure conditions, and durable. [12]

2.2.1. Cement

Cement is the essential component of concrete which, when hydrated, binds the aggregates together to form the hard, strong and monolithic whole that is so useful. Well over 95% of the cement used in concrete throughout the world is Portland cement in its various forms. [25]. The properties of concrete depend on the quantities and qualities of its constituents. Because cement is the most active component of concrete and usually has the greatest unit cost, its selection and proper use are important in obtaining most economically the balance of properties desired for a particular concrete mixture.

Portland cement is hydraulic cement composed primarily of hydraulic calcium silicates and hydraulic cement set and hardens by reacting chemically with water. [7]

2.2.1.1. Types of Cement

Types of Portland cement can be varied by changing the relative proportions of its prominent chemical compounds, by the degree of fineness of the clinker grinding and/or by adding some pozzolanic materials. As a result, there are several types of cement for different purposes. Ordinary Portland cement (OPC), Rapid Hardening Portland cement, Sulphate Resisting Portland Cement, Low heat Portland cement, Portland Pozzolana Cement (PPC). But, only Ordinary Portland cement and Portland Pozzolana Cements are produced in Ethiopia. [7]

A pozzolan is defined in ASTM C 618 as “a siliceous or siliceous and aluminous material, which, in itself possesses little or no cementations value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementations properties.” They are composed of similar materials and react with the products of hydrating cement to create additional cementations binder. Glassy non-crystalline forms of silica, alumina, and iron are principally responsible for the pozzolanic reaction with calcium hydroxide (lime). In concrete, lime results from the hydration of Portland cement. The pozzolanic material can be used to modify and improve the plastic and hardened properties of concrete.

AASHTO M 85, Specification for Portland cement, uses type designations I through V for Portland cement .Type I Portland cement is general-purpose cement suitable for all uses where the special properties of other types are not required. Its uses in concrete include pavements, floors, reinforced concrete buildings, bridges, tanks, reservoirs, pipe, masonry units, and precast concrete products. [7] Type II Portland cement is used where precaution against moderate sulfate attack is important. It is used in normal structures or elements exposed to soil or ground waters where sulfate concentrations are higher than normal but not unusually severe. Type II cement has moderate sulfate resistant properties because it contains no more than 8% tricalcium aluminates. [7]

2.2.1.2. Chemical Composition of Concrete

The crucial components of Portland cement are calcium silicates, which in the manufacturing process are formed by heating a mixture of calcium oxide (CaO) and silicon dioxide (or silica, SiO2) to high temperatures. Both of these occur in the earth's crust in large quantities, the former in various forms of calcium carbonate (CaCO3), e.g. chalk and limestone, and the latter in a variety of mineral forms in sand, clay or shale. [25]

The mixture is then burned in a rotary kiln at a temperature between 1300 and 15000c. The material partially fuses into a clinker which is taken from the kilns, cooled and then passed on to ball mills where gypsum is added and it is ground to the required fineness.

The resulting cement is allowed to contain small strictly limited percentages of materials not required, some disadvantageous for some uses, such as iron oxide and sulfur trioxide. Table 2.1 shows oxide composition ranges for Portland cement indicate a general idea of the composition of cement. [21]

Table 2.1 Shorthand Notation for the Oxides in Portland Cement

Oxide	Shorthand Notation	Common Name	Typical Weight Percent in Ordinary Cement
CaO	C	Lime	63
SiO_2	Si	Silica	22
Al_2O_3	Al	Alumina	6
Fe_2O_3	Fe	Ferric Oxide	2.5
MgO	Mg	Magnesia	2.5
K_2O	K	Alkalis	0.6
Na_2O	Na	Alkalis	0.4
SO_3	S	Sulfur trioxide	2.0
CO_2	C	Carbon dioxide	----
H_2O	H	Water	----

10The four main compounds, sometimes called *phases,* in the cement, are:

- Tricalcium silicate $3CaO.SiO_2$ in short C_3S
- Dicalcium silicate $2CaO.SiO_2$ in short C_2S
- Tricalcium aluminate $3CaO.Al_2O_3$ in short C_3A
- Tetracalcium aluminoferrite 4CaO. Al_2O_3.Fe2O3 in short C_4AF

The chemical composition of Portland cement is customarily reported in terms of the **oxides** of the various elements that are present, using the shorthand notation given in Table 2.1.

Using this notation, the typical compound composition of ordinary Portland cement may be given as shown in Table 2.2

Typical 2.2 Compound Composition of Ordinary Portland Cement

Chemical Formula	Shorthand Notation	Chemical Name	Weight Percent
$3CaO \cdot SiO2$	C3S	Tricalcium silicate	50
$2CaO \cdot SiO2$	C2S	Dicalcium silicate	25
$3CaO \cdot Al2O3$	C3A	Tricalcium aluminate	12
$4CaO \cdot Al2O3 \cdot Fe2O3$	C4AF	Tetracalcium aluminoferrite	8
$CaSO4 \cdot 2H2O$	CSH2	Calcium sulfate dihydrate (gypsum)	3.5

The characteristics of these compounds when cement is hydrated are indicated in Table 2.3. It can be seen that the two calcium silicates are primarily responsible for the strength that the cement will develop upon hydration. The C3A can lead to durability problems when the concrete is in contact with soils or groundwater containing sulfates. By making relatively small changes in the relative proportions of raw materials, one can bring about relatively large changes in the relative proportions of the principal compounds of Portland cement. [12]

Table 2.3 Contribution of Cement Compounds to the Hydration of Portland Cement

Compound	Reaction rate	Heat liberated	Contribution to strength
C_3S	Moderate	High	High
C_2S	Slow	Low	Low initially, high later
$C_3A + CSH_2$	Fast	Very high	Low
$C_4AF + CSH_2$	Moderate	Moderate	Low

2.2.1.3. Hydration of Portland Cement

The hydration reactions that take place between finely ground Portland cement and water is highly complex because the individual cement grains vary in size and composition. As a consequence, the resulting hydration products are also not uniform; their chemical composition and microstructural characteristics vary not only with time but also with their location within the concrete. The basic characteristics of the hydration of Portland cement may be described as follows:

- As long as the individual cement grains remain separated from each other by water, the cement paste remains fluid.
- The products of the hydration reactions occupy a greater volume than that occupied by the original cement grains.

- As the hydration products begin to intergrow, setting occurs.
- As the hydration reactions continue, additional bonds are formed between the cement grains, leading to the strengthening of the system. [12]

The most important components of Portland cement from the strength development point of view are C_2S and C_3S which, on hydration, form the same compounds in differing proportions. $C_3S_2H_3$ is the final product of hydration of both C_2S and C_3S, the reactions of hydration can be written for C_3S and C_2S respectively, as follows. [21]

$$2(3CaO.SiO_2) + 6H_2O \longrightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2$$

$$2(2CaO.SiO_2) + 4H_2O \longrightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2$$

2.2.1.4. Factors Affecting the Rate and Heat of Hydration

The rate of hydration of Portland cement is affected by a number of factors and is briefly discussed as follows: [18]

a) Cement composition: -

The speed with which the chemical reactions proceed depends on the affirmation of the individual compounds to water. The first to react is the aluminates. The rate of hydration of the aluminates can be possibly retarded by varying the percentage of gypsum ($CaSO_4 \cdot 2H_2O$). The amount of gypsum to properly retard the setting varies mainly with the content of C_3A and the fineness of the cement.

In very hot countries, the cement that is used for making concrete should have reduced proportions of the constituents that hydrate rapidly (C_3A and C_3S) with accompanying high rate of heat liberation. The unchecked rate of hydration accompanied by hot climatic conditions will lead to an excessive expansion of the fresh concrete. At later ages, contraction takes place with resulting cracks that will seriously affect the structure. The high heat liberation of the rapid hardening constituents can be put to advantage in very cold regions where freezing and thawing might adversely affect a freshly cast concrete.

b) Fineness of the cement: -

The finer the grinding of the cement, the faster should be the hydration process and vice versa. However, the ultimate degree of hydration is not affected by the fineness of the cement. A finer cement will require not only more water to cover the higher surface area but also relatively more gypsum to retard the speedy hydration of the decreased number of aluminates particles.

c) Water/cement ratio: -

Both the rate of hydration and the heat evolution are affected by the water/cement ratio. The water/cement ratio has practically no influence on the rate of hydration in the first 24 hours after mixing. Later on, the rate of hydration decreases with a decrease in a water/cement ratio.

d) Age of paste: -

It has been understood that the rate of hydration of cement, and hence the heat evolution, is highest at an early age. Depending on the grain size distribution in the cement and the pressure of water, hydration may continue for several years after mixing but at a much-reduced rate as shown typically in Fig.2.1 [7].

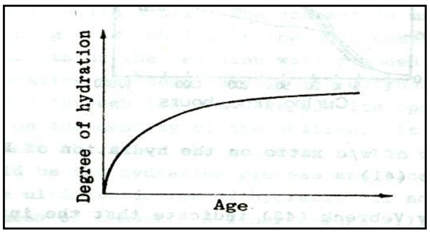

Fig. 2.1 Degree of hydration -vs- age of paste

e) Ambient conditions:-

The rate of hydration of Portland cement is influenced by the ambient temperature, and identical results cannot be expected from specimens that are subjected to different thermal histories. The rate of hydration increases with temperature and this is true only at earlier ages. Ultimately, however, the same degree of hydration is reached irrespective of the curing temperature. The effect of ambient temperature on the heat of hydration is shown in Fig. 2.2 [18].

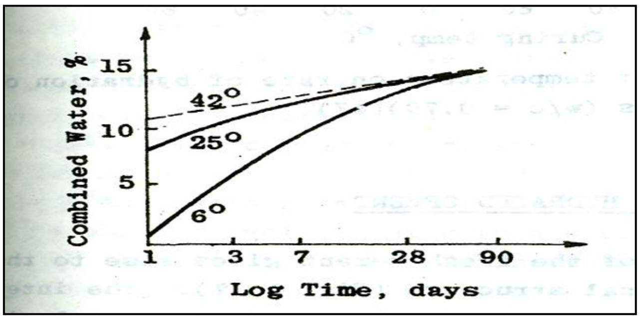

Fig. 2.2 Effect of ambient temperature on the rate of hydration of Portland cement

2.2.2. Aggregate

2.2.2.1. General

ASTM Designation D8 defines aggregate as the inert mineral material such as sand gravel shell slag broke stone or combination of thereof with which the cementing material is mixed to form a mortar or concrete. The definition says the aggregate is intended to be bound or cemented together by some substance. [3]

Aggregates are the filler materials which make up a large portion (roughly 70-75%) of the concrete volume. Considerable care should be taken to provide the best aggregates available.

Aggregate can be obtained from various sources; natural or manufactured. Natural aggregates are taken from natural deposits without a change in their nature during production, with the exception of crushing, sizing grading, or during production. [11]

2.2.2.2. Classification of Aggregate

Aggregates rocks and minerals can be described by their general composition, source, or origin and unit weight:

General composition

Mineral: naturally occurring substance with an orderly structure and defined chemistry.

Rock: a mixture of one or more minerals.

Source

Natural sands and gravels: formed in riverbeds or seabeds and usually dug from a pit, river, lake, or seabed; sands are fine aggregates; gravels are coarser particles.

Manufactured aggregate (crushed stone or sand): quarried in large sizes, then crushed and sieved to the required grading; also, crushed boulders, cobbles, or gravel.

Recycled: made from crushed concrete.

Origin

Igneous: cooled molten material; includes siliceous materials primarily consisting of compounds of silica (for example, granite). Sedimentary: deposits squeezed into layered solids; includes carbonate materials from deposited seashells (for example, limestone). [19]

In accordance with the unit weight

Lightweight aggregate: The unit weight of aggregate is less than 1120 kg/m3. The corresponding concrete has a bulk density less than 1800 kg/m3.

Normal weight aggregate: The aggregate has a unit weight of 1520-1680 kg/m3. The concrete made with this type of aggregate has a bulk density of 2300-2400 kg/m3.

Heavyweight aggregate: The unit weight is greater than 2100 kg/m3. The bulk density of the corresponding concrete is greater than 3200 kg/m3. [21]

2.2.2.3. Physical Property of Aggregate

The aggregate contains 75% of concrete mixture and it affects the property of this mixture. So, if the physical property of aggregate described it manage the property of concrete as a whole. The physical properties like specific gravity, porosity, thermal behavior, and the chemical properties of an aggregate are attributed to the parent material.

The shape, size and surface texture which are essential for concrete workability and bond characteristics between the aggregate and cement paste are, however, attributes of the mode of production. It is, therefore, essential to understanding the physical properties of aggregate and its modes of production in an effort to produce the required quality of concrete at a minimum price. [2]

I. Sampling

Samples shall be representative and certain precautions in sampling have to be made. No detailed procedures can be laid down as the conditions and situations involved in taking samples in the field can vary widely from case to case. Nevertheless, a practitioner can obtain reliable results bearing in mind that the sample taken is to be representative of the bulk of the material.

The main sample shall be made up of portions drawn from different parts of the whole. The minimum number of these portions is described in BS 812; part 105; 1990[12]. In the case of stockpiles, the sample obtained is variable or segregated, a large number of increments should be taken and a larger sample should be dispatched for testing. [21]

II. Strength

The compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained. If the aggregate under test leads to a lower compressive strength of concrete, and in particular if numerous individual aggregate particles appear fractured after the concrete specimen has been crushed, then the strength of the aggregate is lower than the nominal compressive strength of the concrete mix. Such aggregate can be used only in a concrete of lower strength.

In general, the strength of aggregate depends on its composition, texture, and structure. Thus a low strength may be due to the weakness of constituent grains or the grains may be strong but not well knit or cemented together. [27]

III. Particle shape and texture

The external characteristics of the aggregate, in particular, the particle shape and surface texture are the importance of with regard to the properties of fresh and hardened concrete. Ideally, to minimize the amount of cement paste required to provide adequate workability of the fresh concrete, aggregate particles for ordinary concrete should be roughly equidimensional with relatively smooth surfaces, such as most natural sands and gravels. Where natural sands and gravels are unavailable, the crushed stone may be used.

Crushed stone tends to have a rougher surface and to be more angular in shape. As a result, it tends to require rather more cement paste for workability. Whether using natural gravels or crushed stone, however, either flat or elongated particles should be avoided, as they will lead to workability and finishing problems. [12]

The flakiness and elongation tests are useful for general assessment of aggregate but they do not adequately describe the particle shape. The presence of elongated particles in excess of 10 to 15% of the mass of coarse aggregate is generally undesirable, but no recognized limits are laid down. [21]

The shape and texture of fine aggregate have a significant effect on the water requirement of the mix made with the given aggregate. If these properties of fine aggregate are expressed indirectly by it's packing, i.e. by the percentage voids in a loose condition, then the influence on the water requirement is quite definite. The influence of the voids in coarse aggregate is less definite. Flakiness and shape of coarse aggregates have an appreciable effect on the workability of concrete. [21]

IV. Grading of fine and coarse aggregate

Grading or aggregate size distribution is a major characteristic in the concrete mix design. With a given sectional dimension of concrete structural member and spacing of reinforcements, it is in general recommended selecting the maximum possible size of aggregate.

The maximum size and grading are important because they affect: [11]

- The relative volume occupied by aggregate, hence the economy in concrete production
- The surface area of aggregate which determines the amount of water necessary to wet all solids
- The workability of the mixture
- The tendency of segregation
- The porosity and shrinkage

V. Bonding

The bond between aggregate and cement paste is an important factor in the strength of concrete, but the nature of bond is not fully understood. A rougher surface, such as that of crushed particles, results in a better bond due to mechanical interlocking.

In addition, the bond is affected by other physical and chemical properties of aggregate, related to its mineralogical and chemical composition, and to the electrostatic condition of the particle surface. In any case, for good development of bond, it is necessary that the aggregate surface be clean and free from adhering clay particles. [21]

The determination of the quality of bond of aggregate is difficult and no accepted tests exist.

Generally, when the bond is good, a crushed specimen of normal strength concrete should contain some aggregate particles broken right through, in addition to the more numerous ones pulled out from their sockets. An excess of fractured particles might suggest that the aggregate is too weak. [21]

VI. Deleterious substances of aggregate

For satisfactory performance, concrete aggregates should be free of deleterious materials. There are three categories of deleterious substances that may be found in aggregates: impurities, coatings and weak or unsound particles. [21]

Table 2.4: Deleterious substances in aggregates [29]

Deleterious substances	Effect on concrete
Organic impurities	Effects setting and hardening may cause deterioration
Materials finer than 75μm (no. 200) sieve	Affects bond, increase water requirement
Coal, lignite, or other lightweight materials	Affects durability, may cause stains and pop outs
Soft Particles	Affects durability
Clay lumps and friable particles	Affects workability and durability, may cause pop outs
Cherty of less than 2.04 relative density	Affects durability, may cause pop outs
Alkali-reactive aggregates	Causes abnormal expansion, map cracking, and pop outs

2.2.2.4. Coarse-Aggregate Grading

The grading for a given maximum-size coarse aggregate can be varied over a moderate range without appreciable effect on cement and water requirement of a mixture if the proportion of fine aggregate to total aggregate produces concrete of good workability. Mixture proportions should be changed to produce workable concrete if wide variations occur in the coarse-aggregate grading. Since variations are difficult to anticipate, it is often more economical to maintain uniformity in manufacturing and handling coarse aggregate than to reduce variations in gradation.

The maximum size of coarse aggregate is typically 19 mm or 25 mm. An intermediate-sized aggregate, around 9.5 mm, is sometimes added to improve the overall aggregate gradation. [29]

The most commonly available local coarse aggregates are obtained from normal weight crushed basaltic rocks and lightweight volcanic ash, which are a member of a family of igneous rock (scoria or pumice). [2]

2.2.2.5. Fine-Aggregate Grading

The most desirable fine-aggregate grading depends on the type of work, the richness of the mixture, and the maximum size of coarse aggregate. In leaner mixtures, or when small-size coarse aggregates are used, a grading that approaches the maximum recommended percentage passing each sieve is desirable for workability.

In general, if the water-cement ratio is kept constant and the ratio of fine-to-coarse aggregate is chosen correctly, a wide range in grading can be used without a measurable effect on strength. [29]

Aggregate passing through 4.75 mm sieve is defined as fine. They may be natural sand deposited by rivers and crushed stone obtained by crushing stones. [21]

2.2.3. Water

The quality of water is important because impurities in it may interfere with the setting of the cement, may adversely affect the strength of the concrete or cause staining of its surface. For this reason, the suitability of water for mixing and curing purpose should be considered. A clear distinction must be made between the effects of mixing water and the attack on hardened concrete by aggressive water because some of the latter types may be harmless or even beneficial when used in mixing water. [21]

Although water is an essential ingredient, too much water added during mixing results in a weak concrete. Very little water is necessary to cause the hydration process. Therefore, as a general rule, no more water should be added than necessary to make the mix workable.

2.3. Production of fine aggregate

Fine aggregate can be produced or manufactured in different ways and sources. The most conventional way of the fine aggregate manufacturing process is using river sand basins. The construction industry utilizes sand mainly from streambeds, which are commonly derived from quartzo-feldspathic basement rocks, sandy marine sediments, and alluvial deposits. [2]

Fine aggregate can be obtained from various sources; natural or manufactured. Natural aggregates are taken from natural deposits without a change in their nature during production, with the exception of crushing, sizing grading, or during production.

2.3.1. Manufactured/ crushed fine aggregate

Crushed fine aggregate or sand is used for aggregate materials having dimensions less than 5.0mm that are processed from crushed rock or gravel and intended for construction use.

The term sand refers to relatively small particles and there are some variations of sand with regard to particle size.

The use of manufactured aggregates (crushed hard rock) in concrete has been known since the Roman time. In modern technology, natural aggregates have proved to be significantly economical in use, for which reason the extensive use of manufactured aggregates has been concentrated to regions or projects where the availability of natural aggregates has been limited. [27]

There are shortages of the surplus of natural fine aggregates; however, in recent times encouraged a development towards more use of manufactured aggregates in many populated areas, and for several concrete applications. [14] The depletion of natural sand and fines of manufactured aggregate are the main challenge for aggregate producers.

Crushed or manufactured sand has a rough surface texture and the particle size distribution curve can be adjusted in the manufacturing of the material. The crushed sand manufacturing plant can be constructed near to site and it will decrease transportation cost also increase the employment.

Crushed sand is known to increase the strength of concrete over concrete made with equal quantities of river sand. The Compressive strength of crushed sand concrete continues to increase with age for all the percentage of crushed sand contents. [6]

Manufactured sands are made by crushing aggregate to a size appropriate for use as a fine aggregate (< 5.0mm). The crushing process caused the manufactured sand to have an irregular particle shape. These fine particles and irregular shape of the aggregate have detrimental effects on the workability and finish of the concrete. These negative effects have given manufactured sands a poor reputation in the construction industry. [27]

2.3.2. Natural river sand

Rivers sand is a naturally occurring granular material composed of finely divided rock and mineral particles. The composition of sand is highly variable, depending on the local rock sources and conditions, a most common constituent of sand in inland continental settings and non-tropical coastal settings is silica (silicon dioxide, or SiO2), usually in the form of quartz. An individual particle in this range size is termed a sand grain. Sand grains are between gravel and silt. [21]

For the construction industry in Ethiopia river sand is mostly used as fine aggregate for concrete production. And this sand takes out from streambeds, which are commonly derived from quartzo-feldspathic basement rock, sandy marine sediments, and alluvial deposits.

Major natural sand supply for the construction works in and around Addis Ababa is the Awash basin located about 70-120 km southeast of the city. [2] By different mode of transportation the river sand is transported to the site and store in an open environment.

2.4. Characteristics of fine aggregate

Aggregate in the concrete mixture has great influence. This influence provides a technical advantage on concrete which has higher volume stability better than the cement paste alone. So, before using aggregate as concrete making material, it is important to examine whether those aggregates fit for the purpose to which they are intended to be used and tests on site and laboratory should have to be made. Some of the characteristics will be discussed below:

2.4.1. Specific gravity

According to ASTM C 127-84, specific gravity is defined as the ratio of mass (or weight in air) of a unit volume of material to the mass of the same volume of water at the stated temperature. [21]

Specific gravity is an expression of the density of an aggregate. It is the ratio between the weight of the substance and that of the same volume of water. Aggregates contain pores in their structure. Therefore, the specific gravity depends on whether the pores included in the measurement or not. The apparent specific gravity of an aggregate refers to the solid materials excluding the pores, and bulk specific gravity refers to total volume, i.e., including pores of the aggregate.

2.4.2. Sieve analysis

Sieve analysis is the process of dividing a sample of aggregate into fractions of same particle size and its purpose to determine the grading or size distribution of the aggregate. [21]

The grading determines the paste requirement for a workable concrete since the amount of void requires needs to be filled by the same amount of cement paste in a concrete mixture. To obtain a grading curve for aggregate, sieve analysis will be conduct. According to ES C.D3.201, BS882 and ASTM the grading requirement of fine aggregate, are summarized as shown in Table 2.3. [32]

Table 2.5 BS and ASTM grading requirements of fine aggregate

Sieve Size	Percentage of passing %				
	BS882:1973				ASTM standards (C33-78)
	Grading Zone 1	Grading Zone 2	Grading Zone 3	Grading Zone 4	
9.5mm	100	100	100	100	100
4.75mm	90-100	90-100	95-100	95-100	95-100
2.36mm	60-95	75-100	85-100	95-100	80-100
1.18mm	30-70	55-90	75-100	90-100	50-85
600μm	15-34	35-59	60-79	80-100	25-60
300μm	5-20	8-30	12-40	15-50	10-30
150μm	0-10	0-10	0-10	0-15	2-10

2.4.3. Fineness modulus

Fineness modulus is the sum of cumulative percentage retained on the sieves of standard series divided by 100. [21]

The specified sieves are 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600μm, 300 μm, and 150 μm (No. 4, 8, 16, 30, 50, and 100). Note that the lower limit of the specified series of sieves is the 150 μm (No. 100) sieve and that the actual size of the openings in each larger sieve is twice that of the sieve below. The coarser the aggregate size, the higher the FM. For fine aggregate used in concrete, the FM generally ranges from 2.3 to 3.1 as called for in ASTM C 33. [33]

It used for an index to the fineness, coarseness, and uniformity of aggregates. These properties of the aggregate significantly affect the property of the concrete, but it is not an indication of grading since there could be an infinite number of grading which will produce a given fineness modulus. The following limits may be taken as guidance.

- Fine sand: F.M. 2.2 - 2.6
- Medium Sand: F.M. 2.6 - 2.9
- Coarse Sand: F.M. 2.9 - 3.2

Sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete. However, it is clear that one parameter, the average, cannot be representative of a distribution: thus the same fineness modulus can represent an infinite number of totally different size distributions or grading curves.

So, fineness modulus cannot be used to detect slight variations in the aggregate from the same source which could affect the workability of the fresh concrete.

2.4.4. Bulk density

Bulk density can define as unit weight, which is the weight of a given volume of graded aggregate. The unit weight efficiently measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate particles and the voids between them. The unit weight merely is measured by filling a container of known volume and weighing it. However, the degree of tamping or time vibration will change the amount of void space.

Since the weight of the aggregate is dependent on its moisture content, constant moisture content is required. Oven dried aggregate sample used in this test. [1]

The relative bulk density (unit weight) of aggregate commonly used in normal-weight concrete ranges from about 1200 to 1750 kg/m3 (75 to 110 lb/ft3). [29]

The bulk density depends on how densely the aggregate is packed and consequently, on the size distribution and shape of the particles. Thus, for the best purposes, the degree of compaction has to be specified.

2.4.5. Silt content

The material in fine aggregates which is finer than 75µm regarded as silt. Silt content in the sand for the concrete has a severe effect on the quality of the concrete. It mainly affects the workability of the concrete, and also results in the reduction of strength.

Sand is a product of the natural or artificial disintegration of rocks and minerals. Sand is obtained from glacial, river, lake, marine, residual and wind-blown (very fine sand) deposits. These deposits, however, do not provide pure sand. They often contain other materials such as dust, loam, and clay that are finer than sand. Therefore it is necessary that one make a test on the silt content and checks against permissible limits.

A simple test which can be made on site to give a guide to the amount of silt in the natural sand is the 'field settling' test. This test should not be used for crushed rock sands.

According to the Ethiopian Standard, it is recommended to wash the sand or reject if the silt content exceeds a value of 6%. [1]

2.4.6. Moisture content

Aggregates exposed to rain collect considerable amounts of moisture on the surface of the particles, and, except at the surface of stockpile keeps this moisture for a long period of time. The Moisture content must be allowed for in the calculation of batch quantities and of the total water requirements of the mix.[21]

The aggregates in concrete are assumed to be inert materials. But most of the aggregates do not meet this assumption by either absorbing water (dry aggregates) or by releasing it (wet aggregates) to the mix. As a result of this property of aggregates the design water to cement ratio of the mix changes.

Therefore, it is important to determine both the absorption capacity and the moisture content of the aggregate. The moisture content of fine aggregates was determined by oven drying a sample of fine aggregate (500gm) in an oven at a temperature of 110°C for 24hrs and dividing the weight difference by the oven dry weight

2.5. Environmental and technical effect of fine aggregate

2.5.1. Environmental effect of fine aggregate

Natural aggregate is the most common construction material and is used in buildings, civil engineering projects and transport infrastructures such as roads, railways, and airport runways.

So this valuable natural resource must be used carefully and sensibly. When there is a high amount of population and construction production the scarcity will happen because of the high amount of demand. The cost also increases and the resource becomes depleted. [2]

The cumulative effects of uncontrolled sand mining have substantially altered the physical as well as social environment. The environmental effects of natural river sand mining can be generalized as shown below: [23]

A. Reduction of farm and grazing lands.

Farming and animal rearing activities replace by sand and gravel mining this is because for sand and gravel to be extracted, vegetation is destroyed and this vegetation serves as food for cattle. This then denies both animals and inhabitants. Sand mining has not only denied the people in the area their means of livelihood but also to those who practiced agriculture as a way of life, infringed on their cultural heritage.

B. Destruction of the landscape.

Landscape destruction is one of the significant effects of mining in the area. The original landscape has been destroyed and altered as a result of excavated pits and trenches, leaving behind unpleasant sights which as well render the land unsuitable for any productive purpose During the raining season these pits collect and store stagnant water and as such, serve as breeding ground for pests such as mosquitoes and other water-borne insects which in turn can affect the health of the people living in and around the area.

C. The collapse of river bank.

The extraction of sand and gravel around and within the river makes the banks of the river weaker and gradually collapses. This does not only leads to filling of the river channel with sediments but gives room for the water in the river to flow out resulting in erosion which washes away the soil.

D. Deforestation

Mining of sand and gravel resulted in the destruction of vegetation thereby destroying the natural habitats of some animals. Some very important plant species are also destroyed and the soil is exposed to erosion.

E. Water pollution

Sediments from mines running off into the river and wetlands are a significant source of water pollution. Both surface and groundwater quality are been affected by contamination with suspended and dissolved materials. In-stream mining of sand, gravel, and gold has led to the re-suspension of sediments in the water causing the brownish coloration of the water and this water is been consumed by the miners in the area due to lack of alternative source for drinking water.

F. Air Pollution

Air pollution is also one of the environmental impacts observed. The dust particles distribute to the air and that causes the pollution of the environment.

2.5.2. A technical effect of fine aggregate

The natural fine aggregate has an effect on concrete production technically. Some of the technical effects that affect concrete mixtures are shown below. [18]

- The amount of containing fine particles it affects the mix ratio and strength of concrete
- Containing organic and soluble compounds affects setting time and properties of cement
- Containing impurities and clay particles that affect the amount of water and bonding between cement and aggregate
- The presence of organic materials affects the durability of the concrete, therefore, it shortens the life of the concrete product

2.6. Replacement material for natural sand

2.6.1. The need for natural sand be a replacement

In construction industry natural sand is used as an important building material and world consumption of sand in concrete alone is around 1000 million tons per year making it scarce and limited. [26]

The main natural and cheapest sources of sand are riverbeds and these natural resources are depleting very fast. Due to various reasons, good sand is not necessarily readily available and it should be transported long distances. Transportation is a major factor in the delivered price of construction sand. Moving construction sand to the market increases the sale price of the market significantly, due to the high cost of transportation. [27]

Rapid extraction of sand from river bed causing so many problems like losing water retaining soil strata, deepening of the river beds and causing bank slides, loss of vegetation on the bank of rivers, disturbs the aquatic life as well as disturbs agriculture due to lowering the water table in the well etc are some of the examples. [5]

In the current situation, the scarcity of natural or river sand has become a problem for the construction industry in Ethiopia. Due to booming construction activities nationwide, natural or river sand resources are increasingly depleted, and at the same time, its cost is increasingly high. [27] Relative to this, searching for a source of new substitute of fine aggregate for concrete production, which can be replaced naturally or river sand is significant.

2.6.2. Materials used for replacement of natural sand

In the recent year, the construction industry has identified some waste material like fly ash, slag, limestone powder, siliceous stone powder and crush sand for use in traditional concrete. And due to the high rising cost of natural sand, there must need to replace natural sand with artificial sand.]

2.6.2.1. Manufactured Sand

A review of different experimental studies performed by various researchers has been carried out to examine various operational parameters like workability, compressive strength, the tensile strength of concrete with crushed sand as a replacement to the natural sand in that total investigation. The following conclusions are made:

- The concrete with crushed sand performed better than concrete with natural sand as the property of crush sand is better than that of natural sand.
- From our study, it is concluded that different Crushed sand gives different results for compressive strength depending on different quarries and from the study of a different research paper at 40% to 50% replacement of crushed sand the maximum compressive strength is obtained.
- The maximum tensile strength of concrete is obtained at 60% and 70% replacement of natural sand with Crushed sand.
- Manufactured sand offers important economic advantages in regions where the availability of natural sand is scarce or in cities where transportation cost is high as in the case of Addis Ababa and Jimma.
- The mechanical properties of crushed rock sand depend on the source of its raw material hence the selection of quarry is very important for obtaining quality fine aggregate. The crushed rock that was tested satisfied most of the mechanical and physical properties required for concrete. However, it required blending to meet the desired gradation because of excessive fines. [16, 26 & 27]

2.6.2.2. Quarry dust

Quarry dust can be used as an alternative material to the natural river sand and can be introduced as a functional construction material. The physical and chemical properties of quarry dust satisfy the requirements of fine aggregate. [6]

2.6.2.3. Stone Dust

On the basis of the study, it can be concluded that:

- Stone dust is to be used as partial or full replacement of natural fine aggregate in concrete.
- The use of stone dust in concrete is beneficial in a different manner such as environmental aspects, non-availability of good quality of fine aggregate, strength criteria etc.
- The workability of concrete was decreased at increment level of stone dust in concrete which can be maintained by an extra dose of superplasticizer.
- It can be used where setting time is not much important because of the excess dose of superplasticizer increase the setting time. [10]

2.6.2.4. Granite powder

Granite powder can be used as filler as it helps to reduce the total voids content in concrete. Granite powder and quarry rock dust improve pozzolanic reaction. The quarry rock dust and granite powder can be used as 100% substitutes for natural sand in concrete. The compressive, split tensile and durability studies of concrete made of quarry rock dust nearly 15% more than the conventional concrete. The concrete resistance to sulfate attack was enhanced greatly. [13]

2.6.2.5. Waste foundry sand

The replacement of sand with waste foundry sand up to 15% is desirable, as it doesn’t adversely affect the strength properties of concrete. There is a significant increase in shrinkage of concrete with an increase in the percentage of WFS and also with the age of concrete. Mixtures containing waste foundry sand above 30% showed very high shrinkage. From the obtained results it can be concluded that concrete containing waste foundry sand up to 15% can be efficiently used for structural applications. Higher replacements can be tried in non-structural applications like concrete pavements. [15]

2.7. Sandstone

2.7.1. Introduction

Sandstone is a clastic in origin (as opposed to organic, like chalk or coal) sedimentary rock composed mainly of sand-sized (0.0625 to 2 mm) mineral particles or rock fragments. Most sandstone is composed of quartz and or feldspar because these are the most common minerals in earth's crust like sandstone may be of any color. The most common colors are tan, yellow, red, gray and white. Since sandstone beds often form highly visible cliffs and other topographic features, specific colors of sandstone may be strongly identified with particular regions. [30]

Sandstones formed from the cement grains that may be fragments of a pre-existing rock, or else just mono–mineralic crystals the cement binding these grains together are typically calcite, clays and silica. [17]

In Ethiopia, the thickest developments of red bed sandstones are within the Triassic successions; it is called the Adigrat sandstone. These are found predominantly in the northern part of the country, but also in central parts, such as the Ambo (i.e., study area), Bure (Gojam) and Abay area. At present, the exploitation of sandstone for building purpose occurs mainly in the Ambo quarries. [22]

The Ambo sandstone is yellow to red and predominantly fine-grained. The sandstone is quite porous, and therefore easy to split and shape. The color which is reddish at the surface changes into white as the stratification depth continues, the grains are very fine in texture and dusty in dry condition. [28]

2.7.2. Property of sandstone

Quartz framework grains are the dominant minerals in most clastic sedimentary rocks; this is because they have exceptional physical properties, such as hardness and chemical stability. These physical properties allow the quartz grains to survive multiple recycling events, while also allowing the grains to display some degree of rounding. Quartz grains evolve from plutonic rock, which is felsic in origin and also from older sandstones that have been recycled. [30]

Although, sandstones show similar appearances and properties; a geological background may cause differences in color, mineral composition, granulometric properties, pressure strength, and weathering behavior. [19]

On the other hand, mineralogical properties of sandstones could predict their mechanical properties such as the uniaxial compressive strength. [31]

Chemically sandstone is very resistant Mono-Mineralic rock, with silica as the principal. The percentage of each constituent is as follows in table 2.6 in the next page below. [9]

2.7.3. Purpose of sandstone

Sandstone has been used for domestic construction and house-wares since prehistoric times and continues to be used. Sandstone was a popular building material from ancient times. It is relatively soft, making it easy to carve. It has been widely used around the world by constructing temples, homes, and other buildings. [30]

Such quartzitic sandstone, plentiful in Ethiopia, is utilized to manufacture glass and is currently in use for small-scale Glass and Bottle Factory in Addis Ababa. This rock is used as an ornamental stone in the construction of outbuildings of dwellings. Actually, ignimbrite is the most widely used for construction in Addis Ababa. [17]

Table 2.6 chemical constituents of Ambo sandstone

Constituent	Oxide composition	% of the chemical composition
Silica	SiO_2	97.6%
Iron	Fe_2O_3	0.9%
Alumina	Al_2O_3	1%
Magnesia	MgO	0.15%
Traces		0.35%

2.7.4. Previous work and Research on sandstone

"The possibility of sandstone replacing river sand was studied by Paramasivam Suresh Kumar, in Malaysia, Thesis; on "A study on high-performance concrete using sandstone aggregate". From his research, he concludes that locally available sandstone aggregate can be used in concrete production''

"Improvement of Compressive Strength of Specified Concrete with adding Waste Red Sand Stone Powder in place of Fine Aggregate." From this study, they concluded that the red stone dust is the very useful product for replacing fine aggregate from cement concrete of grade M20. Red stone dust is in the form of pulverized product which can be used as simply fine aggregate in making of cement concrete the properties of sand and red sandstone dust are similar. It can be replaced out 30 percent of fine aggregate in cement concrete of grades of

M20 it gives better compressive strength as compared to the conventional concrete of grade of M20.

"Experimental Investigation of Partially Replaced Fine Aggregate with Sandstone Powder in Concrete." this study conclude that The compressive strength, tensile strength and flexural strength values of 75% replaceable sandstone powder are reduced as compared to 50% but more than conventional concrete. So replaceable of sandstone powder up to 50% is safe.

"Suitability of Crushed Jema Sandstone for Concrete Production as Alternative to River Sand." the following conclusions are made and recommendations are forwarded.

- In general, is observed as an increase in strength as the proportion of crushed Jema sandstone is increased. From all grade of concrete mixes, concrete with 100% crushed Jema sandstone proportion was capable of achieving higher compressive strength than concrete with river sand control mix.
- The relative strength gain decreased as the concrete grade increased from C-25 to C-40. This shows that the use of crushed Jema sandstone is more useful for normal strength concrete production.
- Crushed Jema sandstone is made by crushing sandstone rock to sizes appropriate for use as a fine aggregate. During the crushing process, the Jema sandstone has more fine particles that may contribute to improved compressive strength, compared to river sand.
- Crushed Jema sandstone offers a viable alternative to the river sand if the problems associated with the workability of the concrete mix can be resolved by using admixture.
- The crushed Jema sandstone must be first washed and graded to meet the standard requirement of ASTM.

Even though no study yet was done in Ethiopia, Ambo sandstone used as a replacement of river sand in the construction industry. Yotek Construction Company uses this material in ambo site.

2.8. Mix design

The purpose of a concrete mix design is to have economical mix proportions for the available concreting materials which comply with the contract specification in all respects and has adequate workability to be placed in its final position on site.

Every combination of concreting materials will have its own mix design and changes in sources of aggregates, binders and admixtures will have a significant effect on the performance and cost of a concrete. Concrete mix designs should not be used in other geographical areas with dissimilar properties of concrete materials.

There is a different factor that needs to be considered while preparing the mix design. Some of the factors are:- 1/ strength margin, 2/ measurement of workability, 3/ free water, and 4/ W/C ratio, 5/ aggregate type and grading, 6/ cement content and aggregate size. [20]

2.9. Properties of concrete

2.9.1. Properties of fresh concrete

Fresh concrete is also known as plastic concrete. The major Properties of concrete in its plastic state are workability, consistency, segregation, bleeding and Stiffening and Setting.

2.9.1.1. Workability

The strict definition of workability is the amount of useful internal work necessary to produce full compaction. [21] Workability is ease of placing and resistance to segregation of concrete.

Factors that affect workability are:

- Water content
- Shape of aggregates
- Grading of Aggregates
- Size of Aggregates
- Surface Texture of Aggregates
- Air-entraining Agents.

2.9.1.2. Consistency

It refers to ease of flow of concrete and indicates wetness of concrete, and thus workability. Concrete could have dry, plastic, semi-fluid, and fluid consistency. the concrete of plastic consistency can be shaped into a ball, while that of semi-fluid consistency spreads out slowly and without segregation of aggregate. The concrete of fluid consistency spreads out fast and results in segregation of aggregates, and hence unacceptable.

2.9.1.3. Segregation

Segregation or separation of coarse aggregates from the mass of concrete results from:

- Uncontrolled pumping or falling
- Placing underwaters
- Placing concrete in heavily reinforced members

2.9.1.4. Bleeding

Bleeding: is the appearance of water on the concrete surface. As a consequence of bleeding, slum layer will be formed making concrete weak and porous. Slum layer shall be removed before casting new layer.

Measures to minimize bleeding:

- Using well graded and proportioned aggregates
- Increasing amount of cement
- Applying air entering agents
- Reducing the amount of water

2.9.1.5. Stiffening and Setting

Concrete is required to remain plastic for the time to be taken to transport, place, and consolidate it. Temperature influences the stiffening of concrete. That is low-temperature delays while high temperatureacce1erates.the stiffening of concrete.

2.9.2. Properties of harden concrete

The compressive strength of concrete is usually at least ten times its tensile strength, and five to six times its flexural strength. The principal factors governing compressive strength are given below:

- Water-cement ratio is by far the most important factor.
- The age of the cured concrete is also important. Concrete gradually builds strength after mixing due to the chemical interaction between the cement and the water. It is normally tested for its 28-day strength, but the strength of the concrete may continue to increase for a year after mixing.
- The character of the cement, curing conditions, moisture, and temperature. The greater the period of moist storage (100% humidity) and the higher temperature, the greater the strength at any given age.
- Air entrainment, the introduction of very small air voids into the concrete mix, serves to greatly increase the final product's resistance to cracking from freezing-thawing cycles. Most outdoor structures today employ this technique.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Sample location

The sample of Crushed Ambo sandstone was taken from Ambo town and which located in the West Shewa Zone of the Oromia Regional national state, west of Addis Ababa at 125 km. This town has the latitude of 8°59′N and longitude 37°51′E and an elevation of 2101 meters and the experiment was conducted in Addis Ababa Science and Technology University material Laboratory.

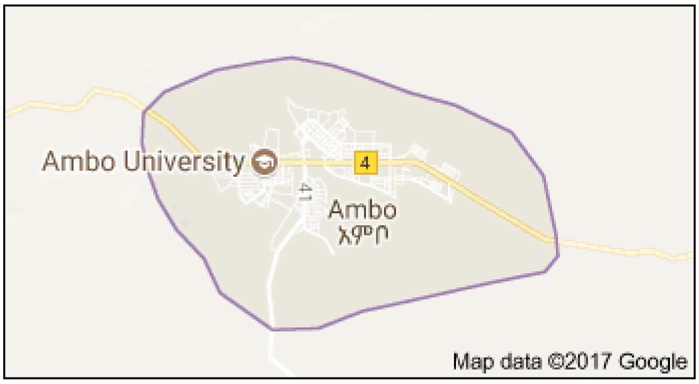

Figure 3.1 Sample Location

3.2. Data Sampling, Collection, and Analysis

3.2.1. Data Sampling and Sample Size

The research has been carried out for six months, which was including from data collection up to the final paper editing.

The experimental design was used for this research during the study period. To provide the most reliable proof the quality of the raw materials of concrete were studied, mainly the quality of natural fine aggregate, crushed ambo sandstone and a combination of both with the same type of cement, coarse aggregate, and water and identified their effect on concrete properties such as workability and compressive strength.

The sample frame or target population of this research was crushed Ambo sandstone which was produced by crushing the Ambo stone to the needed size which is below 4.75mm.

3.2.2. Sampling Technique

The sampling technique used for this research was a non-probability Sampling technique which is the purposive method. This sampling technique was proposed based on the information that the researcher has and the aim or goal of the researcher to be achieved.

3.2.3. Data Collection

Both primary data sources and secondary data sources were used. Secondary data needed for this research was collected from different journals, book, and website during the literature review and primary sources of data for this study was conducted by recording the output of each laboratory tests.

3.2.3.1. Materials for Laboratory Experimental Works

- **Cement: -** “Dangote” Ordinary Portland Cement (OPC) whose Grade is 42.5R, which is locally available cement.
- **Crushed Ambo Sandstone: -** by sieving a 4.75mm maximum nominal size that was produced using ambo stone that taken was taken from sankale quarry site.
- **Natural Coarse aggregate: -** “Legehar" crushed stone which is a 25mm maximum nominal size that was commonly available in Addis Ababa (obtained from Goro site).
- **Sand: -** “Legehar” sand which was commonly available in Addis Ababa (obtained from Metehara).
- **Water: -** Drinkable water (potable water) obtained from Addis Ababa Science and Technology University material Laboratory water supply.

3.2.2.2. Procedure for Laboratory Experimental Works

Stage 1:- Sample Preparation

Figure 3.2 Selecting and quartering of materials

Stage 2: Laboratory tests on the constituent of concrete

- Tests on coarse aggregate according to ASTM C136-96a and ES Standard Procedures. (i.e., sieve analysis, water absorption, unit weight, specific gravity, and moisture content)
- Tests on fine aggregate according to ASTM and ES Standard Procedures. (i.e., sieve analysis, water absorption, unit weight, specific gravity, and moisture content)
- Tests on cement (i.e., Consistency test, initial and final setting time and fineness of cement test).

Figure 3.3 Data recording for material weight

Figure 3.4 Silt content

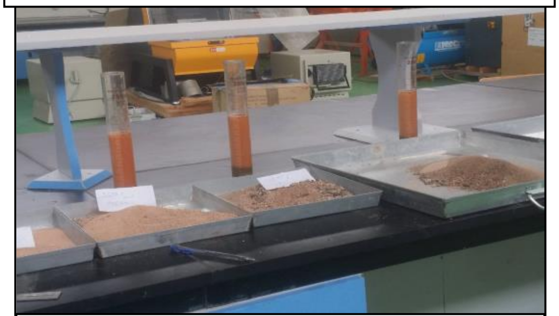

Figure 3.5 Bulk density

Figure 3.6 Moisture content

Figure 3.7 Sieve analysis

Figure 3.8 Specific gravity

Stage 3: Concrete mix design preparation and mixing of concrete

- C-25 Concrete Mix-Design Prepared for each aggregate replacement ratio according to the ACI Methods. The slump test was done to check the workability of the concrete, and also nine samples of concrete cubes were cast for each replacement percent of recycled aggregate in which forty-five cubes samples were cast by using 150mm*150mm*150mm cube.

- De-molding Specimen and coding (identification) the sample concrete cubes done after 24 hrs. And curing of the concrete cube samples proceeded.

Figure 3.9: Casting and Coding

Stage 4: Compressive strength test

After 7, 14 and 28 days cured of the concrete cube sample; the Compressive strength test of the concrete cubes was taken place by using Universal Testing Machine.

Figure 3.10: Curing of Concrete Cubes

Figure 3.11: Compressive Strength Test

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Material Properties

The Physical characteristics of concrete making materials (Cement, Crushed Ambo Sandstone, Fine aggregate, Coarse aggregate, and Water) used for the research were examined, and appropriate mix design was made.

4.1.1. Cement

Table 4.1: Summarized Test Results for Dangote Cement (OPC)

<table>
<tr><th>Item no.</th><th colspan="2">Description</th><th>Test Result</th></tr>
<tr><td>1</td><td colspan="2">Fineness of Cement</td><td>95% passing</td></tr>
<tr><td>2</td><td colspan="2">Specific Gravity</td><td>3.15</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">Cement Consistency Test</td><td>W/C ratio (%)</td><td>32%</td></tr>
<tr><td>Water (gm)</td><td>160</td></tr>
<tr><td>Penetration (mm)</td><td>9.3</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">Setting Time</td><td>Initial</td><td>48 min.</td></tr>
<tr><td>Final</td><td>8hr. 38min.</td></tr>
</table>

Ethiopian standard recommends that the initial setting time for Portland cement not to be less than 45 minutes and the final setting time do not exceed 10 hours. From this experiment, we get the exact penetration value (of 25mm) at 48minutes and the final setting 8hrs 38min hence the initial setting time is approximately acceptable.

4.1.2. Aggregates Used for the Experiment

Aggregate samples were washed to minimize or eliminate the effects of impurities before used for concrete mix and sun-dried on a clean platform. All aggregates tests were done by the Ethiopian standards and conform to the ASTM requirements.

4.1.2.1. Properties of Coarse Aggregate

The aggregates coming from the crusher site (Goro site) and produced in the laboratory was washed thoroughly and dried in air. The size of the coarse aggregate used for experimental investigation was a maximum size of 37 mm diameter, and it was used in all the concrete mix designs. The test findings are shown above in Table 4.2, and also the summary of gradations is shown below in Figure 4.1.

Table 4.2: Summarized Test Results for Coarse Aggregate

Item no.	Description		Test Results
1	Maximum Aggregate Size (mm)	Max.	37.5
		Nominal	25
2	Specific Gravity	Bulk	2.82
		Bulk (SSD)	2.85
		Apparent	2.89
3	Unit Weight (kg/m^3)	Loose	1432
		Compacted	1592
4	Absorption Capacity		0.74%
5	Moisture Content		1.33%
6	Shape		Angular
7	Texture		Rough

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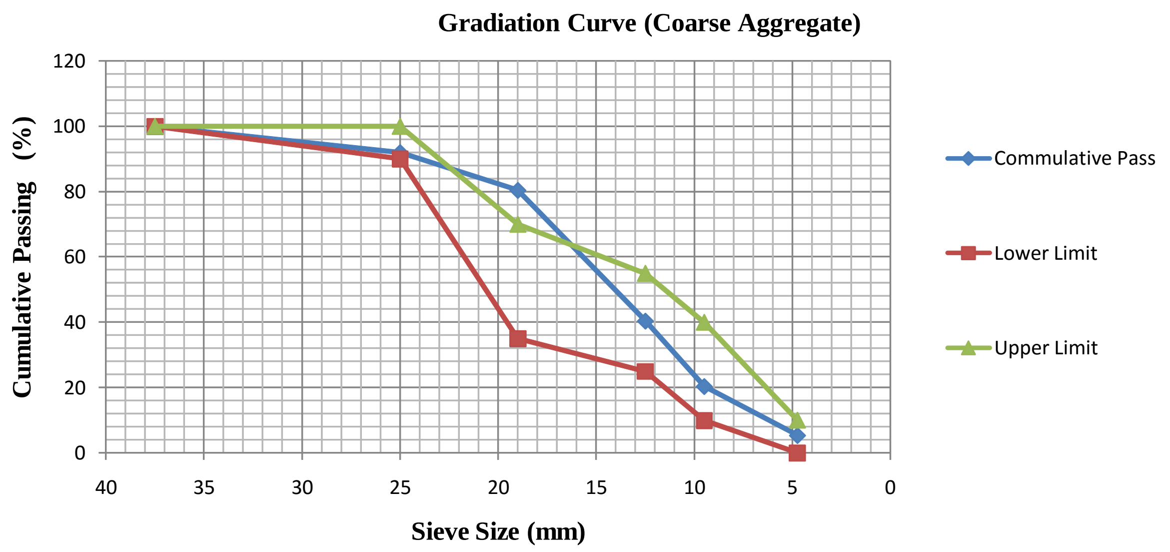

Figure 4.1: Gradation Curve of Coarse Aggregate

The evaluation of the physical properties of coarse aggregate was made by ASTM C 136-96a (Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates) which approximately satisfied the limitation.

4.1.2.2. Properties of Fine Aggregate

To make control of mix for C-25 normal river sand which "Legehar" sand which was commonly available in Addis Ababa (originally obtained from Metehara), was used to prepare the concrete samples. The Crushed Ambo sandstone sand commonly known as "Ambo Dingay" is extracted from Ambo town, which located in the West Shewa Zone of the Oromia Regional national state, west of Addis Ababa at 125 km.

The fine aggregate was dried to be saturated, and surface dry (SSD) state before any test was carried out. Also, the type of fine aggregate used for experimental investigation was the same for all the concrete mix designs because using a single type of fine aggregate ensured that any variations in concrete properties were not due to this material.

In order to design and make a concrete mix, a number of tests were carried out on the above materials. The test performed includes: sieve analysis, bulk and dry density, moisture content, absorption capacity, unit weight, a chemical test like silicate analysis etc. All aggregates tests were done in accordance with the Ethiopian standards and conform to ASTM requirements. The test findings and gradation curve are shown below in Table 4.3 and Figure 4.2.

Table 4.3: Summarized Test Results for Fine Aggregate

Item no.	Description		Test Results (With Different Replacement Levels)				
			100%RS + 0%CAS	0%RS + 100%CAS	50%RS + 50%CAS	75%RS + 25%CAS	25%RS + 75%CAS
1	Specific Gravity	Bulk	2.19	2.20	2.25	2.22	2.19
		Bulk (SSD)	2.21	2.21	2.26	2.23	2.21
		Apparent	2.24	2.23	2.27	2.24	2.23
2	Unit Weight (kg/m^3)	Loose	1364	1412	1488	1428	1470
		Compacted	1400	1426	1574	1548	1560
3	Absorption Capacity		1.07%	0.54%	0.32%	0.32%	0.74%
4	Moisture Content		4.58%	2.78%	4.81%	4.99%	4.6%
5	Silt Content		1.67%	5.05%	5.33%	6%	5.05%
6	Fineness Modulus		2.62	2.52	2.37	2.56	2.37

According to ES C.D3.201, the gradation result of the original sample sand is out of range on sieves 300µm and 150µm size. So, it is blended with finer sand to make it within the range. The grading requirements for fine aggregates according to ES C.D3.201 and, the particle size distribution of original and blended aggregate used for the experiment is shown in Fig 4.2 and Each replacement levels of coarse aggregate gradations together with their curve are shown in Appendix-A

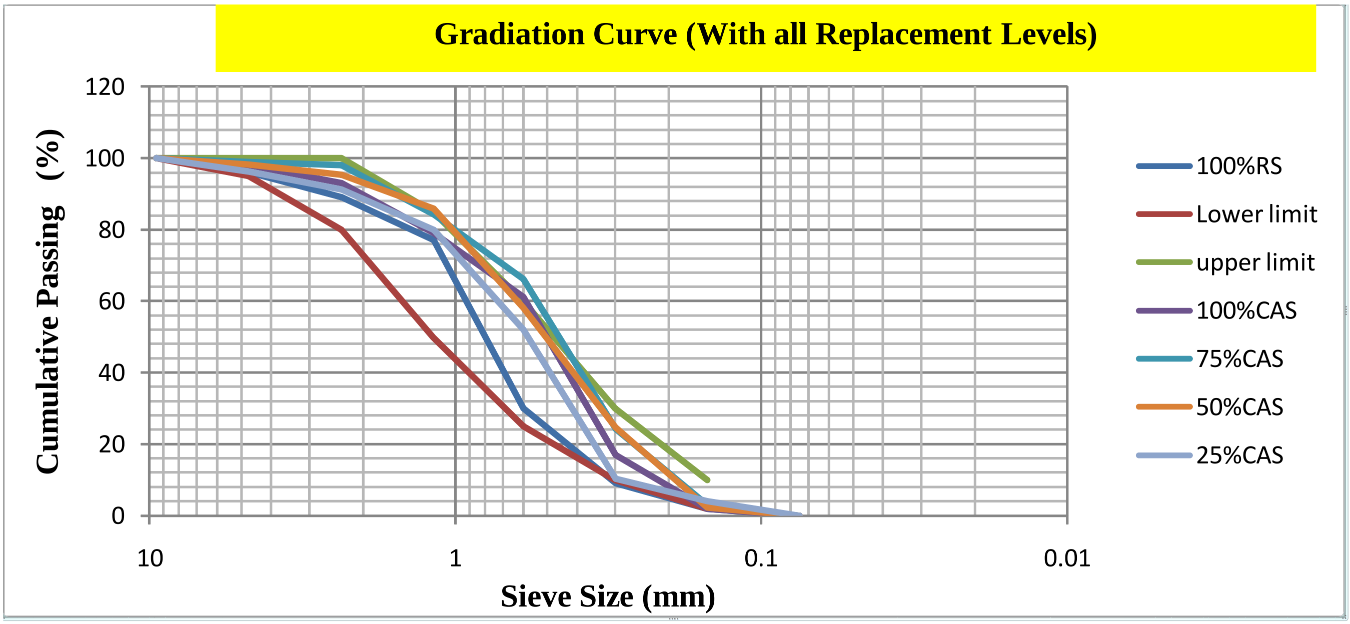

Figure 4.2: Gradation Curve of Fine Aggregate with all replacement

4.1.3. Water

Drinkable water (potable water) obtained from Addis Ababa Science and Technology University, Material Laboratory, which is supplied from the Addis Ababa water supply and sewerage authority, was used for all concrete mix.

4.2. Mix Proportions

To determine the effects of Crushed Ambo Sandstone and a combination with natural fine aggregate (river sand) at different replacement levels on properties of concrete, different mixes with a characteristic strength of normal strength (C-25) were prepared.

4.2.1. Concrete Mix Design

In this research work, the ACI Method of mix design was used in designing the mix proportions. On this bases, five different types of mix-design were prepared based on the crushed Ambo sandstone replacement levels which are; 100%RS+0%CAS, 0%RS+100%CAS, 50%RS+50%CAS, 75%RS+25%CAS, and 25%RS+75%CAS. For each concrete batch produced, it was decided that nine cubes were to be cast to allow for 7, 14 and 28 days test for the compressive strength test. As a result, the total of 45 concrete cube specimens was produced.

For all the concrete mixes, the same w/c ratio was used to ensure that any variations in the properties of the concrete were because of the Crushed Ambo Sandstone used and not any other external factors. A summary of mix proportions for 1m^3 of concrete mixes is shown below in Table 4.4.

Table 4.4: Summarized Mix Proportions

Coarse Aggregate Replacement Levels	Cement Type	W/C Ratio	Water (kg)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)
100%RS+0%CAS	Dangote OPC	0.50	164.84	358	765.01	1113.09
0%RS+100%CAS	Dangote OPC	0.50	175.15	358	683.70	1193.75
50%RS+50%CAS	Dangote OPC	0.50	160.84	358	739.97	1129.22
75%RS+25%CAS	Dangote OPC	0.50	163.09	358	700.78	1226.01
25%RS+75%CAS	Dangote OPC	0.50	173.61	358	792.98	1129.22

4.2.2. Preparation of Specimens and Mixing Procedure

Cement, which was produced locally by Dangote cement factory, was used throughout the mixing process and graded aggregate fulfilling Ethiopian standards (EBCS) which conform to ASTM requirements are also used for mix preparation of the samples.

The preparation of the constituent materials was made by using weight measurement. After determining the relative amounts of materials be used for specimens, the aggregates and cement were mixed dry for one minute by using a mobile mixer. After the addition of water, all the material mixed for another two minutes. Then immediately after mixing the concrete, the workability is measured filling the standard slump cone with three layers and rodding each layer 25 times according to ASTM C143. The specimens were then put on a firm and level surface of prepared molds and well compacted in three layers with the help of a tamping rode, by rodding each layer 25 times and also side compaction of the molds was carried out by using tire hammer. After compaction, the top surface is finished using a trowel.

The concrete mix was cast in the molds for the first 24 hours. After that, the concrete was removed from the molds and placed in a water bath at a temperature of 23 ± 1^{o}C for curing to take place until the testing age was reached. After 7, 14 and 28 days of curing period the concrete cubes specimens were removed from the water bath then placed in dry surface until the specimens were surface dried; in the meantime, the concrete cubes specimens were weighted to determine the unit weight of the concrete cube. Finally, the specimens were tested by standard compression testing machine.

It was stated above that the main objectives of the laboratory test specimens were to:

- Study the suitability of crushed Ambo sandstone on the general properties of concrete in both the fresh and hardened state and compare the result with that of concrete produced using river sand.
- Check if the properties of crushed Ambo sandstone is compatible with different standard
- Investigate the effect of percentage replacement of river sand by crushed Ambo sandstone on different properties concrete.
- Determine the rate of strength gain for the concrete with and without crushed Ambo sandstone.

In the following sections, the test results are presented and evaluated in light of the requirements of concrete strength and workability.

4.3. Crushed Ambo sandstone

4.3.1.1. Sieve analysis

Fresh and hardened properties of concrete can be affected by the gradation of aggregate. Improper gradation can affect the air content, slump, and result in excessive voids in the hardened concrete. Sieve analyses of aggregates were performed according to ASTM.

The results of sieve analysis, as expected, have shown that crushed Ambo sandstone contains a larger amount of fine materials than the natural sand. The grading of the natural and Ambo sandstone sand is different requiring variable aggregate blending. According to ASTM C33-03, the fine aggregate should not be more than 45 % passing in any sieve and retained on the next consecutive sieves, while its fineness modulus should not be less than 2.3 and not be more than 3.1. From the sieve analysis results except for sieve no.600µm all satisfy the grading requirement of ES.C.D3.201 in conformation with ASTM C33. The fineness modulus is inside the range provided in ASTM. So, the material is standardized for the mix in this research. The results of all sieve analysis for all aggregate samples used in the concrete mix are attached in annex A.

4.3.1.2. Silt content

The silt content of the original sample was found to be 13.8% which was above the allowable limit. According to the Ethiopian standard it is recommended to wash sand or reject if the silt content exceeds a value of 6%. Therefore it was necessary to wash it to reduce the silt content. After performing the procedure, the Silt content of crushed Ambo Sandstone, fine aggregate showed was less than the allowable 6%. The results of silt content are attached in Annex A.

4.3.1.3. Specific gravity and absorption capacity

The specific gravity (relative density) and absorption capacity of natural and recycled coarse aggregates were determined according to ASTM C 127-88. The results of different types of aggregate properties tests are shown in Table 4.3. The specific gravity of CAS was similar with that of natural fine aggregate. The results of specific gravity, absorption and moisture content for all aggregate samples used in the mix are attached in Appendix-A.

4.3.2. Concrete test

4.3.2.1. Fresh Concrete Properties

Five different concrete mixes were designed with varying levels of CAS replacement. The CAS content used to replace a portion of the natural fine aggregate varies from 25-100 % with a 0% CAS replacement as the control mix (Mix-1). Control mix made with conventional fine aggregate (River Sand) was required to facilitate the proper comparison between CAS concrete and RS concrete. The control specimens also facilitated as a reference for comparison. The results of the fresh concrete properties are provided below in Table 4.5. This table shows that the slump value of different concrete mixes remained unaffected due to the utilization of different replacement levels of CAS.

The concrete mix which contains Ambo sandstone is relatively harsher than the other mixes in all the mix series this is mainly because of: (1) because it is finer it has a larger surface area to volume ratio, in turn, it needs more water and more paste to fill the spaces thoroughly; (2) it will decrease the mobility of the mass due to varying combination of sizes.

Table 4.5: Properties of Fresh Concrete

Mix-no.	Fine Aggregate Replacement Levels	Slump (mm)
Mix-1	100%RS+0%CAS	35
Mix-2	0%RS+100%CAS	30
Mix-3	50%RS+50%CAS	32
Mix-4	75%RS+25%CAS	33
Mix-5	25%RS+75%CAS	31

4.3.2.2. Hardened Concrete Properties

The most common tests carried out on concrete specimens is compressive strength test due to the fact that: a) structural design codes are based mainly on compressive strength of concrete; b) it is assumed that most of the important properties of concrete are directly related to compressive strength, and c) the test is easy and relatively inexpensive to carry out.

The compressive strength of the concrete specimens was determined by testing concrete cubes of size 150mm according to ASTM C39-90. All specimens were weighed and measured to determine the area of the cube and density of the concrete. The hardened properties of the concrete have been determined at the ages of 7, 14 and 28 days. At each age, a minimum of three specimens was tested to ensure the accuracy of test results. The use of Ambo sandstone by replacing wholly or partially the natural river sand had shown an effect on the compressive strength of concrete. The results are presented in Figure 4.3 and Table 4.6.

The compressive strength test result for C-25 of 25%, 50%,75% and 100% crushed Ambo sandstone replaced concrete at the 28day have been shown 0.17%, -3.15 %, 10% and 17.24% from the control concrete mix.

The test results showed below that for all concrete mix proportions, concrete with 100% crushed Ambo sandstone was capable of achieving a higher compressive strength than concrete with river sand control mix. The use of crushed Ambo sandstone for normal strength concrete production is more useful and special cares have to be taken to ensure that the concrete mix achieves a suitable finish. The raw data for the compressive strength values are shown in Annex B.

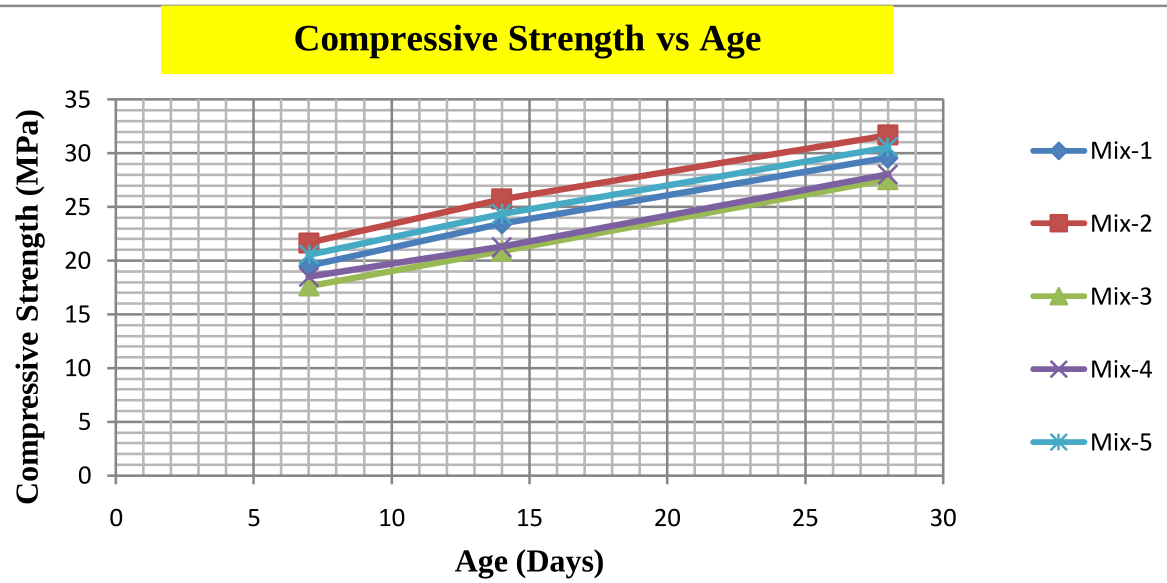

Figure 4.3 Compressive Strength vs Age

Table 4.6: Summary of Mean Compressive Strength Results of Different Concrete Mixes

Mix-no.	Fine Aggregate Replacement Levels	Age					
		7 day Strength		14 day Strength		28 day Strength	
Mix-1	100%RS+0%CAS	19.51	Control	23.46	Control	29.58	Control
Mix-2	0%RS+100%CAS	21.66	11.01%	26.74	13.98%	34.68	17.24%
Mix-3	50%RS+50%CAS	17.62	-9.69%	22.89	-2.42%	28.54	-3.15%
Mix-4	75%RS+25%CAS	18.5	-5.18%	23.27	-0.8%	29.63	0.17%
Mix-5	25%RS+75%CAS	20.54	5.28%	25.32	7.9%	31.54	10%

4.4. Economic aspects

It can be formulated that natural aggregate production in Ethiopia has been and will continue to be a local business based on easily accessible natural deposits. Most of the aggregate quarries are owned by the farmers on a private land, and they sell their product or lease the quarry to contractors for different works.

The major sand supply for the construction works in and around Addis Ababa is the Awash basin located about 70-120 km southeast of the city. The method of quarrying sand is generally very old and the producers do not attempt to clean and grade the sand right from the source. [2]

Due to the booming of construction activities in our country, natural resources and are increasingly depleted, and its cost is becoming increasingly high. Also as can be seen from the experience of aggregate manufacturing in Ethiopia, the true cost of aggregate material is influenced by various factors, yet production and transportation costs play the major role. But the economic impact of Ambo sandstone sand has not been deeply investigated and it was difficult to get the exact figure about its production cost.

Table 4.7 Distribution Cost per m3 of fine aggregates in Addis Ababa and Ambo

Sand type	Cost per m3	One Sino truck (16m3) Pick-up Price	Location
Crushed Ambo Sandstone (CAS)	140 ETB	2240 ETB	Ambo (quarry site)
River Sand (originally from Ziway Area)	300-400 ETB (at site)	7500-8000 ETB	Legeher Market

Table 4.7 is generated from the fact that from Addis Ababa to Ambo is approximately equal to 114 km distance from the Ambo Sandstone quarry site. As is observed from the table, Ambo Sandstone has a relative economical advantage over river sand once; it will be used for construction projects around Addis Ababa. There is also a potential for cost savings in many areas where river sands are not locally available and have to be hauled long distances, however, detail review of all other implications should be considered when taking alternative material for concrete production.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Crushed Ambo sandstone as a partial or full replacement of river sand for C-25 concrete was studied and after the research work is done, the following conclusions are made and recommendations are forwarded.

- In general, is observed as an increase in strength as the proportion of crushed Ambo sandstone is increased. From all grade of concrete mixes, concrete with 100% crushed Ambo sandstone proportion was capable of achieving higher compressive strength than concrete with river sand control mix.

- Crushed Ambo sandstone is made by crushing sandstone rock to sizes appropriate for use as a fine aggregate. During the crushing process, the Ambo sandstone has more fine particles that may contribute to improved compressive strength, compared to river sand.

- Crushed Ambo sandstone offers a viable alternative to the river sand if the problems associated with the workability of the concrete mix can be resolved by using admixture.

- The silt contents of crushed Ambo Sandstone (CAS) from Senkele quarry site indicated 14.28%. Based on Ethiopian standard, silt content exceeds 6%, the sand would be washed or rejected as a part of the concrete. Hence, after performing the procedure to remove silt content, it was found out that the silt content reduced to 5.3%, less than the allowable maximum of 6%. Therefore, Crushed Ambo Sandstone (CAS) is suitable for concrete mix production and strong determination.

To sum up, Crushed Ambo Sandstone (CAS) fits the standard specifications with all laboratory test results except silt and clay contents. Therefore, before using it in a concrete mix, it must be washed thoroughly which can be served as a suitable replacement for river sand.

5.2. Recommendations

Based on the study conducted on the partial replacement of natural river sand with crushed Ambo sandstone for production C-25 concrete, the following recommendation was made for the concerned bodies:

The construction industry should do more works for the announcement ambo sandstone using as river sand. Because it has a huge economic impact for construction at Ambo town and also for the capital, that has a shortage of river sand.

The contractor, Designers, and concerned parties should recognize the effects of crushed Ambo sandstone on concrete water demand and concrete durability.

The contractor, Designers, and concerned parties should control the crushed Ambo sandstone washed before used for concrete mix.

Concerned authorities should up to date information about the location and existing of Ambo sandstone in addition with the potential of availability of this material.

5.3. Future research directions

1. Economical aspects by using crushed Ambo sandstone as replacement of natural river sand for concrete mix.
2. Environmental effects by using the natural deposits for construction purpose
3. Other materials that used to replacing the natural material using construction industry.

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APPENDIX

A. Material properties and Test results

A.1. Properties of cement

Item no.	Description		Test Result
1	Fineness of Cement		95% passing
2	Specific Gravity		3.15
3	Cement Consistency Test	W/C ratio (%)	32%
		Water (gm)	160
		Penetration (mm)	9.3
4	Setting Time	Initial	48 min.
		Final	8hr. 38min.

A.2.Properties of Fine Aggregate

A.2.1. 100% River Sand

- **Gradation test for Fine Aggregate 100% River Sand**

Sieve Size (mm)	Weight Retained (gm)	Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)	ASTM Limit	
					Min	Max
9.5				100	100	100
4.75	38.63	3.863	3.863	96.137	95	100
2.36	70.07	7.007	10.87	89.13	80	100
1.18	120.12	12.012	22.882	77.118	50	85
0.6	470.54	47.054	52.946	30.064	25	60
0.3	210.01	21.001	78.999	9.063	10	30
0.15	70.36	7.036	92.964	2.027	2	10
0.075	20.27	2.027		0		
PAN	0	0		0		
TOTAL	**1000**		**262.524**			
		FM	**2.62524**			

$$FM = \frac{\sum \% \text{ Cumulative Coarser}}{100}$$

FM = 262.524/100 = **2.63**

- **Silt Content for Fine Aggregate 100%RS**

Silt Content (%) = $\frac{\text{Original Dry Mass (Total Wt) - Dry Mass after Washing}}{\text{Dry Mass after Washing}}$ * 100

Silt Content (%) = (1000 – 983.3)/1000 * 100 = 1.67%

(0.5/30ml)*100= **1.67%**

- **Specific Gravity and Absorption test for Fine Aggregate 100% RS**

- Weight of oven dry sample in air “A” (gm) = 494.7
- Weight of pycnometer filled with water “B” (gm) = 1422.2
- Weight of pycnometer + sample + water “C” (gm) = 1696.3

Bulk Specific Gravity = A/(B+500-C) = **2.19**

Bulk Specific Gravity (SSD) = 500/(B+500-C) = **2.21**

Apparent Specific Gravity = A/(A+B-C) = **2.24**

Absorption Percent = (500-A/A)*100 = **1.07%**

- **Unit Weight for Fine Aggregate 100% RS**

Loosely Filled

- Weight of container “A” (kg) = 3.99
- Weight of container + sample “B” (kg) = 10.81
- Volume of container “C” (m^3) = 0.005

Unit Weight (kg/m^3) = B-A/C = **1364**

Compacted

- Weight of container “A” (kg) = 3.99
- Weight of container + sample “B” (kg) = 10.99
- Volume of container “C” (m^3) = 0.005

Unit Weight (kg/m^3) = B-A/C = **1400**

- **Moisture Content for Fine Aggregate 100% RS**
- Weight of original sample “A” (gm) = 500
- Weight of oven dry sample “B” (gm) = 478.1

Moisture Content (%) = (A-B/B)*100 = **4.58%**

A.2.2. 100% Crushed Ambo Sandstone

- **Gradation test for Fine Aggregate 100% Crushed Ambo Sandstone**

Sieve Size (mm)	Weight Retained (gm)	Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)	ASTM Limit	
					Min	Max
9.5				100	100	100
4.75	20.02	2.002	2.002	97.998	95	100
2.36	49.53	4.953	6.955	93.045	80	100
1.18	139.76	13.97	20.925	79.075	50	85
0.6	179.01	17.9	82.1	61.175	25	60
0.3	442.58	44.23	55.77	16.945	10	30
0.15	149.12	14.91	85.09	2.035	2	10
0.075	19.98	1.99		0		
PAN	0	0		0		
TOTAL	**1000**		**252.842**			
		FM	**2.52842**			

$$FM = \frac{\sum \%\ \text{Cumulative Coarser}}{100}$$

FM = 252.842/100 = **2.52**

- **Silt Content for Fine Aggregate**

$$\text{Silt Content (\%)} = \frac{\text{Original Dry Mass (Total Wt) - Dry Mass after Washing}}{\text{Dry Mass after Washing}} * 100$$

Silt Content (%) = (1000 – 994.95)/1000 * 100 = 5.05%

(1.5/30ml)*100= **5%**

- **Specific Gravity and Absorption test for Fine Aggregate 100% CAS**
  - Weight of oven dry sample in air “A” (gm) = 497.3
  - Weight of pycnometer filled with water “B” (gm) = 1425.2
  - Weight of pycnometer + sample + water “C” (gm) = 1699.3

Bulk Specific Gravity = A/(B+500-C) = **2.20**

Bulk Specific Gravity (SSD) = 500/(B+500-C) = **2.21**

Apparent Specific Gravity = A/(A+B-C) = **2.23**

Absorption Percent = (500-A/A)*100 = **0.54%**

- **Unit Weight for Fine Aggregate 100% CAS**

Loosely Filled

- Weight of container "A" (kg) = 3.99
- Weight of container + sample "B" (kg) = 11.05
- Volume of container "C" (m^3) = 0.005

Unit Weight (kg/m^3) = B-A/C = **1412**

Compacted

- Weight of container "A" (kg) = 3.99
- Weight of container + sample "B" (kg) = 11.12
- Volume of container "C" (m^3) = 0.005

Unit Weight (kg/m^3) = B-A/C = **1426**

- **Moisture Content for Fine Aggregate 100% CAS**
- Weight of original sample "A" (gm) = 500
- Weight of oven dry sample "B" (gm) = 486.1

Moisture Content (%) = (A-B/B)*100 = **2.78%**

A.2.3. 75% River sand and 25% CAS

- **Silt Content for Fine Aggregate 75% RS and 25% CAS**

$$\text{Silt Content (\%)} = \frac{\text{Original Dry Mass (Total Wt) - Dry Mass after Washing}}{\text{Dry Mass after Washing}} * 100$$

Silt Content (%) = (1000 – 940)/1000 * 100 = 6%

(1.8/30ml)*100= **6%**

- **Gradation test for Fine Aggregate 75% RS and 25% CAS**

Sieve Size (mm)	Weight Retained (gm)	Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)	ASTM Limit	
					Min	**Max**
9.5				100	100	100
4.75	37	3.7	3.7	96.3	95	100
2.36	50.13	5.013	8.713	91.287	80	100
1.18	112.6	11.26	19.973	80.027	50	85
0.6	280	28	72	52.027	25	60
0.3	416.24	41.624	58.376	10.403	10	30
0.15	63.76	6.376	93.624	4.027	2	10
0.075	40.27	4.027		0		
PAN	0	0		0		
TOTAL	**1000**		**256.386**			
		FM	**2.56386**			

$$FM = \sum \frac{\%\ \text{Cumulative Coarser}}{100}$$

FM = 256.386/100 = **2.56**

- **Specific Gravity and Absorption test for Fine Aggregate 75% RS and 25% CAS**
    - Weight of oven dry sample in air “A” (gm) = 498.4
    - Weight of pycnometer filled with water “B” (gm) = 1420.7
    - Weight of pycnometer + sample + water “C” (gm) = 1696.5

Bulk Specific Gravity = A/(B+500-C) = **2.22**

Bulk Specific Gravity (SSD) = 500/(B+500-C) = **2.23**

Apparent Specific Gravity = A/(A+B-C) = **2.24**

Absorption Percent = (500-A/A)*100 = **0.32%**

- **Unit Weight for Fine Aggregate 75% RS and 25% CAS**

Loosely Filled

- Weight of container “A” (kg) = 3.99
- Weight of container + sample “B” (kg) = 11.13
- Volume of container “C” (m^3) = 0.005

Unit Weight (kg/m^3) = B-A/C = **1428**

Compacted

- Weight of container "A" (kg) = 3.99
- Weight of container + sample "B" (kg) = 11.73
- Volume of container "C" (m^3) = 0.005

Unit Weight (kg/m^3) = B-A/C = **1548**

- **Moisture Content for Fine Aggregate 75% RS and 25% CAS**
  - Weight of original sample "A" (gm) = 500
  - Weight of oven dry sample "B" (gm) = 463

Moisture Content (%) = (A-B/B)*100 = **7.99%**

A.2.4. 50% RS and 50% CAS

- **Gradation test for Fine Aggregate 50% RS and 50% CAS**

Sieve Size (mm)	Weight Retained (gm)	Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)	ASTM Limit	
					Min	Max
9.5				100	100	100
4.75	17.8	1.78	1.78	98.22	95	100
2.36	29	2.9	4.68	95.32	80	100
1.18	94	9.4	14.08	85.92	50	85
0.6	278.5	27.85	72.15	58.07	25	60
0.3	333.06	33.3	66.7	24.77	10	30
0.15	223.96	22.396	77.604	2.374	2	10
0.075	23.68	2.368		0		
PAN	0	0		0		
TOTAL	**1000**		**236.994**			
		FM	**2.36994**			

$$FM = \frac{\sum \% \text{ Cumulative Coarser}}{100}$$

FM = 236.994/100 = **2.37**

- **Silt Content for Fine Aggregate**

$$\text{Silt Content (\%)} = \frac{\text{Original Dry Mass (Total Wt) - Dry Mass after Washing}}{\text{Dry Mass after Washing}} * 100$$

Silt Content (%) = (1000 – 946.7)/1000 * 100 = 5.33%

(1.6/30ml)*100= **5.33%**

- **Specific Gravity and Absorption test for Fine Aggregate 50% RS and 50% CAS**
    - Weight of oven dry sample in air “A” (gm) = 498.4
    - Weight of pycnometer filled with water “B” (gm) = 1420.9
    - Weight of pycnometer + sample + water “C” (gm) = 1699.5

    Bulk Specific Gravity = A/(B+500-C) = **2.25**

    Bulk Specific Gravity (SSD) = 500/(B+500-C) = **2.26**

    Apparent Specific Gravity = A/(A+B-C) = **2.27**

    Absorption Percent = (500-A/A)*100 = **0.32%**

- **Unit Weight for Fine Aggregate 50% RS and 50% CAS**

    Loosely Filled

    - Weight of container “A” (kg) = 3.99
    - Weight of container + sample “B” (kg) = 11.43
    - Volume of container “C” (m^3) = 0.005

    Unit Weight (kg/m^3) = B-A/C = **1488**

    Compacted

    - Weight of container “A” (kg) = 3.99
    - Weight of container + sample “B” (kg) = 11.86
    - Volume of container “C” (m^3) = 0.005

    Unit Weight (kg/m^3) = B-A/C = **1574**

- **Moisture Content for Fine Aggregate 50% RS and 50% CAS**
    - Weight of original sample “A” (gm) = 500
    - Weight of oven dry sample “B” (gm) = 459.5

    Moisture Content (%) = (A-B/B)*100 = **8.81%**

A.2.5. 25% RS and 75% CAS

- **Gradation test for Fine Aggregate 25% RS and 75% Crushed Ambo Sandstone**

Sieve Size (mm)	Weight Retained (gm)	Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)	ASTM Limit	
					Min	Max
9.5				100	100	100
4.75	10	1	1	99	95	100
2.36	10	1	2	98	80	100
1.18	137.5	13.75	15.75	84.25	50	85
0.6	180	18	82	66.25	25	60
0.3	418.5	41.85	58.15	24.4	10	30
0.15	214	21.4	78.6	3	2	10
0.075	30	3		0		
PAN	0	0		0		
TOTAL	**1000**		**237.5**			
		FM	**2.375**			

$$FM = \frac{\sum \% \text{ Cumulative Coarser}}{100}$$

FM = 237.5/100 = **2.37**

- **Silt Content for Fine Aggregate 25% RS and 75%CAS**

$$\text{Silt Content (\%)} = \frac{\text{Original Dry Mass (Total Wt) - Dry Mass after Washing}}{\text{Dry Mass after Washing}} * 100$$

Silt Content (%) = (1000 – 943.3)/1000 * 100 = 5.05%

(1.7/30ml)*100= **5.67%**

- **Specific Gravity and Absorption test for Fine Aggregate 25% RS and 75%CAS**
    - Weight of oven dry sample in air "A" (gm) = 496.3
    - Weight of pycnometer filled with water "B" (gm) = 1423.2
    - Weight of pycnometer + sample + water "C" (gm) = 1697.3

Bulk Specific Gravity = A/(B+500-C) = **2.19**

Bulk Specific Gravity (SSD) = 500/(B+500-C) = **2.21**

Apparent Specific Gravity = A/(A+B-C) = **2.23**

Absorption Percent = (500-A/A)*100 = **0.74%**

- **Unit Weight for Fine Aggregate 25% RS and 75%CAS**

Loosely Filled

- Weight of container “A” (kg) = 3.99
- Weight of container + sample “B” (kg) = 11.34
- Volume of container “C” (m^3) = 0.005

Unit Weight (kg/m^3) = B-A/C = **1470**

Compacted

- Weight of container “A” (kg) = 3.99
- Weight of container + sample “B” (kg) = 11.79
- Volume of container “C” (m^3) = 0.005

Unit Weight (kg/m^3) = B-A/C = **1560**

- **Moisture Content for Fine Aggregate 25% RS and 75%CAS**
  - Weight of original sample “A” (gm) = 500
  - Weight of oven dry sample “B” (gm) = 436.3

Moisture Content (%) = (A-B/B)*100 = **14.6%**

A.3.Properties of Coarse Aggregate

- **Gradation test for Coarse Aggregate**

Sieve Size (mm)	Weight Retained (gm)	Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)	ASTM Limit	
					Min	Max
37.5				100	100	100
25	80	8	8.64	92	90	100
19	1157	11.57	46.91	80.43	35	70
12.5	400	40	86.96	40.43	25	55
9.5	200	20	96.63	20.43	10	40
4.75	150	15	99.74	5.43	0	10
PAN	13	0.13	100	5.3		
TOTAL	**2000**					

- **Specific Gravity and Absorption test for Coarse Aggregate**
  - Weight of oven dry sample in air “A” (gm) = 2066.2
  - Weight of saturated surface dry specimen in air “B” (gm) = 2081.6

- Weight of saturated surface dry specimen in water “C” (gm) = 1350.3

Bulk Specific Gravity = A/(B-C) = **2.82**

Bulk Specific Gravity (SSD) = B/(B-C) = **2.85**

Apparent Specific Gravity = A/A-C = **2.89**

Absorption Percent = (B-A/A)*100 = **0.74%**

- **Unit Weight for Coarse Aggregate**

Loosely Filled

- Weight of container “A” (kg) = 3.99
- Weight of container + sample “B” (kg) = 11.15
- Volume of container “C” (m^3) = 0.005

Unit Weight (kg/m^3) = B-A/C = **1432**

Compacted

- Weight of container “A” (kg) = 3.99
- Weight of container + sample “B” (kg) = 11.95
- Volume of container “C” (m^3) = 0.005

Unit Weight (kg/m^3) = B-A/C = **1592**

- **Moisture Content for Coarse Aggregate**

- Weight of original sample “A” (gm) = 2000
- Weight of oven dry sample “B” (gm) = 1973.8

Moisture Content (%) = (A-B/B)*100 = **1.33%**

B. Mix Design

Mix Design-1 (for 100% RS)

- **Required Material Information**

No	Material Properties	Coarse Aggregate	Fine Aggregate
1	Unit Weight	1592kg/m^3	1400 kg/m^3
2	Fineness Modulus	-	2.63
3	Specific Gravity	2.85	2.21
4	Absorption	0.74%	1.07%
5	Moisture Content	1.33%	4.58%

- **Assuming Non-Air-Entrained Concrete**

Step 1: Choice of Slump

Based on the recommended values of a slump for various types of construction as given by ACI 211.1-81:-

- 25-50mm (minimum slump possible) is taken. The selected slump is 45mm, considering ease of placement, bleeding, and segregation of concrete.

Step 2: Maximum Size of Aggregate

Based on the sieve analysis result:-

- Maximum Aggregate size 37.5mm
- Maximum Nominal Aggregate size 25mm

Step 3: Estimation of Mixing Water and Air Content

Based on the approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregates as given by ACI 211.1-81:-

- Water content requirement for maximum nominal aggregate size 25mm, for a slump of 25-50mm, and Non-Air-Entertained concrete is 179 kg/m^3.

Step 4: Estimation of Water/Cement Ratio

Based on the Relation between water/cement ratio and average compressive strength of concrete as given by ACI 211.1-81:-

- The effective water/cement ratio for the specified compressive strength of 25 MPa is 0.5.

Step 5: Calculation of Cement Content

By using results from step 3 & 4:-

- Cement Content (Kg/m^3) = $\frac{\text{weight of water}}{\text{water/cement ratio}}$ = 179/0.5 = 358 kg/m^3

Step 6: Estimation of Coarse Aggregate

Based on the dry bulk volume of coarse aggregate per unit of volume of concrete as given by ACI 211.1-81:-

- The volume of coarse aggregate for the maximum nominal aggregate size of 25mm and finesse modulus of 2.63 is 0.69 m^3 (using linear interpolation).
- Coarse Aggregate (Kg/m^3) = unit wt.* volume = 1592 *0.69 = 1098.48 kg/m^3

Step 7: Estimation of Fine Aggregate

By using absolute volume method:-

- Water = 179/(1*1000) = 0.179 m^3
- Cement = 358/(3.15*1000) = 0.11 m^3
- Coarse Aggregate = 1098.48 /(2.85*1000) = 0.38 m^3
- Fine Aggregate = (1 m^3-0.179 m^3-0.11 m^3-0.38 m^3)*2.21*1000 = 731.51 kg/m^3

Step 8: Adjustment for Moisture Content

- Water = 179-[731.51 *(0.0458-0.0107)]-[1098.48 *(0.0133-0.0074)] = 146.84 kg
- Coarse Aggregate = 1098.48 *(1+0.0133) = 1113.09 kg
- Fine Aggregate = 731.51 *(1+0.0458) = 765.01 kg

Step 9: Laboratory Weight Adjustment

For the laboratory trial batch production (9 cubes + 1 cube wastage = 10 cubes):-

- Total Volume = (0.15*0.15*0.15)*10 = 0.034 m^3

Material Type	Adjusted Quantity	Weight (kg)
Water	0.034*146.84	4.99
Cement	0.034*358	12.17
Coarse Aggregate	0.034*1113.09	37.84
Fine Aggregate	0.034*765.01	26.01

Step 10: Compressive Strength Test

No	Test Age (days)	Dimensions (m)			Weight (gm)	Volume (cm^3)	Failure Load (kN)	Comp. Strength (MPa)	Unit Weight (gm/cm^3)
		L	W	H					
1	7	15.00	15.00	15.00	8055	3375	472.2	19.53	2.38
2		15.00	15.00	15.00	8045	3375	461.2	18.29	2.38
3		15.00	15.00	15.00	8060	3375	475.8	20.71	2.38
						Mean	469.73	19.51	2.38
1	14	0.15	0.15	0.15	7.92	$(0.15)^3$	535.06	22.17	2.34
2		0.15	0.15	0.15	7.97	$(0.15)^3$	539.62	23.01	2.36
3		0.15	0.15	0.15	8.02	$(0.15)^3$	547.17	25.20	2.37
						Mean	540.61	23.46	2.35
1	28	15.00	15.00	15.00	8155	3375	693.20	30.81	2.42
2		15.00	15.00	15.00	8264	3375	690.18	28.32	2.44
3		15.00	15.00	15.00	8071	3375	691.47	29.61	2.39
						Mean	691.08	29.58	2.42

Mix Design-2 (for 100% CAS)

- **Required Material Information**

No	Material Properties	Coarse Aggregate	Fine Aggregate
1	Unit Weight	$1592kg/m^3$	$1426\ kg/m^3$
2	Fineness Modulus	-	2.52
3	Specific Gravity	2.85	2.21
4	Absorption	0.74%	0.54%
5	Moisture Content	1.33%	2.78%

- **Assuming Non-Air-Entrained Concrete**

Step 1: Choice of Slump

Based on the recommended values of a slump for various types of construction as given by ACI 211.1-81:-

- 25-50mm (minimum slump possible) is taken. The selected slump is 45mm, considering ease of placement, bleeding, and segregation of concrete.

Step 2: Maximum Size of Aggregate

Based on the sieve analysis result:-

- Maximum Aggregate size 37.5mm
- Maximum Nominal Aggregate size 25mm

Step 3: Estimation of Mixing Water and Air Content

Based on the approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregates as given by ACI 211.1-81:-

- Water content requirement for maximum nominal aggregate size 25mm, for a slump of 25-50mm, and Non-Air-Entertained concrete is 179 kg/m^3.

Step 4: Estimation of Water/Cement Ratio

Based on the Relation between water/cement ratio and average compressive strength of concrete as given by ACI 211.1-81:-

- The effective water/cement ratio for the specified compressive strength of 25 MPa is 0.5.

Step 5: Calculation of Cement Content

By using results from step 3 & 4:-

- Cement Content (Kg/m^3) = $\dfrac{\text{weight of water}}{\text{water/cement ratio}}$ = 179/0.5 = 358 kg/m^3

Step 6: Estimation of Coarse Aggregate

Based on the dry bulk volume of coarse aggregate per unit of volume of concrete as given by ACI 211.1-81:-

- The volume of coarse aggregate for the maximum nominal aggregate size of 25mm and finesse modulus of 2.52 is 0.74 m^3 (using linear interpolation).
- Coarse Aggregate (Kg/m^3) = unit wt.* volume = 1592 *0.74 = 1178.08 kg/m^3

Step 7: Estimation of Fine Aggregate

By using absolute volume method:-

- Water = 179/(1*1000) = 0.179 m^3
- Cement = 358/(3.15*1000) = 0.11 m^3
- Coarse Aggregate = 1178.08 /(2.85*1000) = 0.41 m^3

- Fine Aggregate = (1 m^3-0.179 m^3-0.11 m^3-0.41 m^3)*2.21*1000 = 665.21kg/m^3

Step 8: Adjustment for Moisture Content

- Water = 179-[665.21 *(0.0278-0.0054)]-[1178.08 *(0.0133-0.0074)] = 157.15 kg
- Coarse Aggregate = 1178.08 *(1+0.0133) = 1193.75kg
- Fine Aggregate = 665.21 *(1+0.0278) = 683.70kg

Step 9: Laboratory Weight Adjustment

For the laboratory trial batch production (9 cubes + 1 cube wastage = 10 cubes):-

- Total Volume = (0.15*0.15*0.15)*10 = 0.034 m^3

Material Type	Adjusted Quantity	Weight (kg)
Water	0.034*157.15	5.34
Cement	0.034*358	12.17
Coarse Aggregate	0.034*1193.75	40.58
Fine Aggregate	0.034*683.70	23.25

Step 10: Compressive Strength Test

No	Test Age (days)	Dimensions (cm)			Weight (gm)	Volume (cm^3)	Failure Load (kN)	Comp. Strength (MPa)	Unit Weight (gm/cm^3)
		L	W	H					
1	7	15.00	15.00	15.00	7905	3375	531.06	20.46	2.34
2		15.00	15.00	15.00	7995	3375	535.34	21.17	2.36
3		15.00	15.00	15.00	8070	3375	539.50	23.35	2.39
						Mean	535.47	21.66	2.36
1	14	15.00	15.00	15.00	8220	3375	549.63	26.39	2.43
2		15.00	15.00	15.00	8264	3375	558.51	27.93	2.44
3		15.00	15.00	15.00	8017	3375	545.06	25.92	2.37
						Mean	551.06	26.74	2.41
1	28	15.00	15.00	15.00	8205	3375	738.80	32.84	2.43
2		15.00	15.00	15.00	8355	3375	740.13	35.21	2.47
3		15.00	15.00	15.00	8365	3375	745.39	35.99	2.47
						Mean	739.93	34.68	2.45

Mix Design-3 (75% RS and 25% CAS)

- **Required Material Information**

No	Material Properties	Coarse Aggregate	Fine Aggregate
1	Unit Weight	1592kg/m^3	1548 kg/m^3
2	Fineness Modulus	-	2.56
3	Specific Gravity	2.85	2.23
4	Absorption	0.74%	0.32%
5	Moisture Content	1.33%	7.99%

- **Assuming Non-Air-Entrained Concrete**

Step 1: Choice of Slump

Based on the recommended values of a slump for various types of construction as given by ACI 211.1-81:-

- 25-50mm (minimum slump possible) is taken. The selected slump is 45mm, considering ease of placement, bleeding, and segregation of concrete.

Step 2: Maximum Size of Aggregate

Based on the sieve analysis result:-

- Maximum Aggregate size 37.5mm
- Maximum Nominal Aggregate size 25mm

Step 3: Estimation of Mixing Water and Air Content

Based on the approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregates as given by ACI 211.1-81:-

- Water content requirement for maximum nominal aggregate size 25mm, for a slump of 25-50mm, and Non-Air-Entertained concrete is 179 kg/m^3.

Step 4: Estimation of Water/Cement Ratio

Based on the Relation between water/cement ratio and average compressive strength of concrete as given by ACI 211.1-81:-

- The effective water/cement ratio for the specified compressive strength of 25 MPa is 0.5.

Step 5: Calculation of Cement Content

By using results from step 3 & 4:-

- Cement Content (Kg/m^3) = $\frac{\text{weight of water}}{\text{water/cement ratio}}$ = 179/0.5 = 358 kg/m^3

Step 6: Estimation of Coarse Aggregate

Based on the dry bulk volume of coarse aggregate per unit of volume of concrete as given by ACI 211.1-81:-

- The volume of coarse aggregate for the maximum nominal aggregate size of 25mm and finesse modulus of 2.56 is 0.76 m^3 (using linear interpolation).
- Coarse Aggregate (Kg/m^3) = unit wt.* volume = 1592 *0.76 = 1209.92 kg/m^3

Step 7: Estimation of Fine Aggregate

By using absolute volume method:-

- Water = 179/(1*1000) = 0.179 m^3
- Cement = 358/(3.15*1000) = 0.11 m^3
- Coarse Aggregate = 1209.92 /(2.85*1000) = 0.42 m^3
- Fine Aggregate = (1 m^3-0.179 m^3-0.11 m^3-0.42 m^3)*2.23*1000 = 648.93 kg/m^3

Step 8: Adjustment for Moisture Content

- Water = 179-[648.93 *(0.0799-0.0032)]-[1209.92 *(0.0133-0.0074)] = 122.09 kg
- Coarse Aggregate = 1209.92 *(1+0.0133) = 1226.01 kg
- Fine Aggregate = 648.93 *(1+0.0799) = 700.78 kg

Step 9: Laboratory Weight Adjustment

For the laboratory trial batch production (9 cubes + 1 cube wastage = 10 cubes):-

- Total Volume = (0.15*0.15*0.15)*10 = 0.034 m^3

Material Type	Adjusted Quantity	Weight (kg)
Water	0.034*122.09	4.15
Cement	0.034*358	12.17
Coarse Aggregate	0.034*1226.01	41.68
Fine Aggregate	0.034*700.78	23.83

Step 10: Compressive Strength Test

No	Test Age (days)	Dimensions (m)			Weight (gm)	Volume (cm^3)	Failure Load (kN)	Comp. Strength (MPa)	Unit Weight (gm/cm^3)
		L	W	H					
1	7	15.00	15.00	15.00	8080	3375	467.26	19.40	2.39
2		15.00	15.00	15.00	8005	3375	453.24	18.15	2.37
3		15.00	15.00	15.00	7993	3375	450.1	17.95	2.36
Mean							453.96	18.50	2.37
1	14	15.00	15.00	15.00	8355	3375	545.5	24.73	2.47
2		15.00	15.00	15.00	8180	3375	539.64	23.84	2.42
3		15.00	15.00	15.00	7995	3375	530.17	21.24	2.36
Mean							23.27	23.27	2.41
1	28	15.00	15.00	15.00	7925	3375	587	26.09	2.34
2		15.00	15.00	15.00	8055	3375	762.60	32.86	2.38
3		15.00	15.00	15.00	7985	3375	696.82	29.94	2.36
Mean							696.35	29.63	2.36

Mix Design-4 (50% RS and 50% CAS)

- **Required Material Information**

No	Material Properties	Coarse Aggregate	Fine Aggregate
1	Unit Weight	1592kg/m^3	1574 kg/m^3
2	Fineness Modulus	-	2.37
3	Specific Gravity	2.85	2.26
4	Absorption	0.74%	0.32%
5	Moisture Content	1.33%	8.81%

- **Assuming Non-Air-Entrained Concrete**

Step 1: Choice of Slump

Based on the recommended values of a slump for various types of construction as given by ACI 211.1-81:-

- 25-50mm (minimum slump possible) is taken. The selected slump is 45mm, considering ease of placement, bleeding, and segregation of concrete.

Step 2: Maximum Size of Aggregate

Based on the sieve analysis result:-

- Maximum Aggregate size 37.5mm
- Maximum Nominal Aggregate size 25mm

Step 3: Estimation of Mixing Water and Air Content

Based on the approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregates as given by ACI 211.1-81:-

- Water content requirement for maximum nominal aggregate size 25mm, for a slump of 25-50mm, and Non-Air-Entertained concrete is 179 kg/m^3.

Step 4: Estimation of Water/Cement Ratio

Based on the Relation between water/cement ratio and average compressive strength of concrete as given by ACI 211.1-81:-

- The effective water/cement ratio for the specified compressive strength of 25 MPa is 0.5.

Step 5: Calculation of Cement Content

By using results from step 3 & 4:-

- Cement Content (Kg/m^3) = $\frac{\text{weight of water}}{\text{water/cement ratio}}$ = 179/0.5 = 358kg/m^3

Step 6: Estimation of Coarse Aggregate

Based on the dry bulk volume of coarse aggregate per unit of volume of concrete as given by ACI 211.1-81:-

- The volume of coarse aggregate for the maximum nominal aggregate size of 25mm and finesse modulus of 2.37 is 0.7 m^3 (using linear interpolation).
- Coarse Aggregate (Kg/m^3) = unit wt.* volume = 1592 *0.7 = 1114.4 kg/m^3

Step 7: Estimation of Fine Aggregate

By using absolute volume method:-

- Water = 179/(1*1000) = 0.179 m^3
- Cement = 358/(3.15*1000) = 0.11 m^3
- Coarse Aggregate = 1114.4 /(2.85*1000) = 0.39 m^3

- Fine Aggregate = (1 m^3-0.179 m^3-0.11 m^3-0.39 m^3)*2.26*1000 = 725.46 kg/m^3

Step 8: Adjustment for Moisture Content

- Water = 179-[725.46 *(0.0881-0.0032)]-[1114.4 *(0.0133-0.0074)] = 110.84kg
- Coarse Aggregate = 1114.4 *(1+0.0133) = 1129.22 kg
- Fine Aggregate = 725.46 *(1+0.02) = 739.97 kg

Step 9: Laboratory Weight Adjustment

For the laboratory trial batch production (9 cubes + 1 cube wastage = 10 cubes):-

- Total Volume = (0.15*0.15*0.15)*10 = 0.034 m^3

Material Type	Adjusted Quantity	Weight (kg)
Water	0.034*110.84	3.77
Cement	0.034*358	12.17
Coarse Aggregate	0.034*1129.22	38.39
Fine Aggregate	0.034*739.97	25.16

Step 10: Compressive Strength Test

No	Test Age (days)	Dimensions (m)			Weight (gm)	Volume (cm^3)	Failure Load (kN)	Comp. Strength (MPa)	Unit Weight (gm/cm^3)
		L	W	H					
1	7	15.00	15.00	15.00	7990	3375	453.37	18.20	2.36
2		15.00	15.00	15.00	7910	3375	447.58	16.71	2.34
3		15.00	15.00	15.00	7950	3375	450.25	17.95	2.35
						Mean	450.11	17.62	2.35
1	14	15.00	15.00	15.00	8075	3375	541.50	24.06	2.39
2		15.00	15.00	15.00	8050	3375	531.83	23.70	2.38
3		15.00	15.00	15.00	7970	3375	522.15	20.91	2.36
						Mean	531.82	22.89	2.37
1	28	15.00	15.00	15.00	8190	3375	669.40	29.75	2.42
2		15.00	15.00	15.00	8040	3375	668.20	28.36	2.38
3		15.00	15.00	15.00	8014	3375	663.72	27.51	2.37
						Mean	668.33	28.54	2.39

Mix Design-5 (25% RS and 75%CAS)

- **Required Material Information**

No	Material Properties	Coarse Aggregate	Fine Aggregate
1	Unit Weight	1592kg/m^3	1560 kg/m^3
2	Fineness Modulus	-	2.37
3	Specific Gravity	2.85	2.21
4	Absorption	0.74%	0.74%
5	Moisture Content	1.33%	14.6%

- **Assuming Non-Air-Entrained Concrete**

Step 1: Choice of Slump

Based on the recommended values of a slump for various types of construction as given by ACI 211.1-81:-

- 25-50mm (minimum slump possible) is taken. The selected slump is 45mm, considering ease of placement, bleeding, and segregation of concrete.

Step 2: Maximum Size of Aggregate

Based on the sieve analysis result:-

- Maximum Aggregate size 37.5mm
- Maximum Nominal Aggregate size 25mm

Step 3: Estimation of Mixing Water and Air Content

Based on the approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregates as given by ACI 211.1-81:-

- Water content requirement for maximum nominal aggregate size 25mm, for a slump of 25-50mm, and Non-Air-Entertained concrete is 179 kg/m^3.

Step 4: Estimation of Water/Cement Ratio

Based on the Relation between water/cement ratio and average compressive strength of concrete as given by ACI 211.1-81:-

- The effective water/cement ratio for the specified compressive strength of 25 MPa is 0.5.

Step 5: Calculation of Cement Content

By using results from step 3 & 4:-

- Cement Content (Kg/m^3) = $\dfrac{\text{weight of water}}{\text{water/cement ratio}}$ = 179/0.5 = 358 kg/m^3

Step 6: Estimation of Coarse Aggregate

Based on the dry bulk volume of coarse aggregate per unit of volume of concrete as given by ACI 211.1-81:-

- The volume of coarse aggregate for the maximum nominal aggregate size of 25mm and finesse modulus of 2.37 is 0.7 m^3 (using linear interpolation).

- Coarse Aggregate (Kg/m^3) = unit wt.* volume = 1592 *0.7 = 1114.4 kg/m^3

Step 7: Estimation of Fine Aggregate

By using absolute volume method:-

- Water = 179/(1*1000) = 0.179 m^3

- Cement = 358/(3.15*1000) = 0.11 m^3

- Coarse Aggregate = 1114.4 /(2.85*1000) = 0.39 m^3

- Fine Aggregate = (1 m^3-0.179 m^3-0.11 m^3-0.39 m^3)*2.21*1000 = 709.41 kg/m^3

Step 8: Adjustment for Moisture Content

- Water = 179-[709.41 *(0.146-0.0074)]-[1114.4 *(0.0133-0.0074)] = 74.11 kg

- Coarse Aggregate = 1114.4 *(1+0.0133) = 1129.22 kg

- Fine Aggregate = 709.41 *(1+0.146) = 812.98 kg

Step 9: Laboratory Weight Adjustment

For the laboratory trial batch production (9 cubes + 1 cube wastage = 10 cubes):-

- Total Volume = (0.15*0.15*0.15)*10 = 0.034 m^3

Material Type	Adjusted Quantity	Weight (kg)
Water	0.034*74.11	2.52
Cement	0.034*358	12.17
Coarse Aggregate	0.034*1129.22	38.39
Fine Aggregate	0.034*709.41	24.12

Step 10: Compressive Strength Test

No	Test Age (days)	Dimensions (m)			Weight (gm)	Volume (cm^3)	Failure Load (kN)	Comp. Strength (MPa)	Unit Weight (gm/cm^3)
		L	W	H					
1	7	15.00	15.00	15.00	7985	3375	500.01	20.22	2.36
2		15.00	15.00	15.00	8005	3375	500.80	22.25	2.37
3		15.00	15.00	15.00	7890	3375	499.52	19.15	2.33
						Mean	500.10	20.54	2.35
1	14	15.00	15.00	15.00	8355	3375	550.19	26.83	2.47
2		15.00	15.00	15.00	7905	3375	541.50	23.06	2.34
3		15.00	15.00	15.00	8236	3375	545.38	26.07	2.44
						Mean	545.69	25.32	2.41
1	28	15.00	15.00	15.00	8014	3375	673.19	29.16	2.37
2		15.00	15.00	15.00	8040	3375	682.83	31.74	2.38
3		15.00	15.00	15.00	8128	3375	758.60	33.72	2.40
						Mean	680.30	31.54	2.38

C. Sample Photos